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Los Angeles County Sanitation Districts
Whittier, CA

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WINDROW AND STATIC PILE COMPOSTING OF MUNICIPAL SEWAGE SLUDGES

by

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County Sanitation Districts of Los Angeles County
Whittier, California 90601

Contract No. 14-12-150

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16. ABSTRACT

Research was conducted on composting anaerobically digested and centrifuge dewatered sewage sludge from 1975 through 1980. Windrow and static pile composting processes were evaluated; new methods were employed using deeper windrows and aerated static piles were constructed without using wood chips as a bulking agent. Parameters considered included temperature elevation, microorganism inactivation, moisture and volatile solids content, windrow size and turning frequency, percent and type of bulking agents, and odor and dust control. The influence of the above parameters, and a comparison of windrow and static pile composting are discussed. Windrow composting achieved more consistent pathogen and parasite inactivations within a wide range of operating parameters than did the aerated static piles. A report on the fate of viruses during composting of sewage solids, a review of the problem, and results of field studies is included in the appendix.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and soil and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This report presents design details, operating experiences, and operating and performance data for windrow and static pile composting of dewatered anaerobically digested primary sludge. Consideration of the operational results presented herein is recommended for design engineers, facility planners, and municipalities contemplating the feasibility of a sewage sludge composting operation.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

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ABSTRACT

Increased residential growth in the vicinity of the Los Angeles County Sanitation Districts' (LACSD) Joint Water Pollution Control Plant (JWPCP) and increased dewatered sludge production necessitated research to upgrade sludge composting operations. This composting research had three distinct phases in response to changes in sludge production and characteristics. The research was conducted on anaerobically digested-centrifuge dewatered, primary sludge using either the windrow or static pile composting processes. Performance factors found important in evaluating the composting process include temperature elevation, microorganism inactivation, and moisture and volatile solids content. Important operational factors include windrow size and turning frequency, percent of finish compost recycle or bulking agents, and odor and dust emissions.

For conditions at the JWPCP, (i.e. sludge characteristics, available bulking agents, mild weather, and scale of operation), windrow composting produced results superior to static pile composting. Windrow operations were simpler and product quality was better. The windrow composting process reduces pathogenic organisms densities to low levels and the product is dry enough for subsequent handling and packaging as a base for soil conditioners. Windrow size is the most important operational parameter. Composting performance improved dramatically by using windrows 1.2 to 1.5 m (4 to 5 ft) high, instead of the smaller windrows, 0.7 to 1.1 m (2.5 to 3.5 ft) high used in the earlier studies.

This report was submitted in partial fulfillment of Contract No. 14-12-150 by the County Sanitation Districts of Los Angeles County, California, under the sponsorship of the U.S. Environmental Protection Agency. Additional funding was provided by the State of California and the Federal government through the Clean Water Grants program. This report covers the test period from September 1975 to June 1980, and work was completed as of September 1983.

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SECTION 1

INTRODUCTION

Composting is a biological process in which organic matter is broken down under aerobic and thermophilic conditions into a humus-type end product with byproducts of carbon dioxide, water and heat. Contrary to many other ultimate disposal schemes for sewage sludge, composting results in a stable product that can be used as a soil conditioner. Many municipalities are considering it as an alternative to other methods of final sewage sludge treatment.

In an effort to comply with Federally mandated sludge treatment at the Joint Water Pollution Control Plant (JWPCP) in Carson, California, the County Sanitation Districts of Los Angeles County has conducted various composting research projects since 1972. The sludge used in these projects was anaerobically digested and dewatered with centrifuges. In the early stages of this project, only windrow composting was studied. But when production of dewatered sludge increased and sludge characteristics changed, more research was conducted to improve the windrow composting operation and to evaluate other composting methods such as aerated static piles. This report describes three phases of research on windrow composting and a study of aerated static piles.

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SECTION 2

CONCLUSIONS

Sludge composting research conducted since 1975 has helped produce an effective full-scale windrow composting operation at the JWPCP. Research indicated that windrow composting of JWPCP's anaerobically digested primary sludge produced results superior to those of the aerated static pile composting process. This conclusion is based on achieving consistently the temperature elevations needed for microorganism inactivation and sludge drying, with simpler operations. The major operational parameters for composting at the JWPCP are windrow size, type and quantity of bulking agent, and turn frequency. Odor control and microorganism regrowth were often the controlling output parameters.

Full-scale operation and research studies of windrow composting at JWPCP were very successful from June 1972 until December 1976, when sludge production and characteristics were significantly changed with the addition of basket centrifuges for more complete sludge dewatering. Windrow composting methods used previously to compost the existing scroll centrifuge cake were inadequate for successful composting of this new sludge, which had a much higher moisture content and finer solids. Research conducted on the windrow and aerated static pile composting processes from January 1977 through November 1977 proved only marginally successful. But in June 1978, the use of larger windrows produced significantly improved process reliability and performance. Early composting studies at the JWPCP used shallow windrows 0.7 to 1.1 m (2.5 to 3.5 ft) high. Studies after June 1978 indicated that the use of windrows 1.2 to 1.5 m (4 to 5 ft) high would help assure good temperature elevation and therefore acceptable microorganism destruction. Deep windrow composting became possible because of the development of a new composter (Scarab)* that would adequately process windrows up to 1.5 m (5 ft) high. Deep windrows have the added advantage of requiring less land to compost a given amount of sludge (1).

Significant findings with respect to other factors influencing windrow composting include: 1) a windrow turning frequency of about three times per week results in a well-mixed, aerated pile, 2) mixture ratios of 0.84 to 1.68 m^3 of recycled finished compost per metric ton of dewatered sludge cake (1 to 2 yd^3/short ton) will provide the proper total solids content and sludge handling properties for successful windrow composting, and 3) the use of alternate bulking agents such as rice hulls and wood shavings improved material handling characteristics for the compost mixture as a result of lower bulk density, and indicated possibilities for shorter drying times; these additives were non-recoverable, but are desirable in the final product.

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* Note: Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Because the JWPCP composting operation is located near a residential area, odor and dust control are of prime importance. Some possible control methods include halting of windrow turning during times of adverse meteorological conditions or increased odor complaints, use of maximum buffer zones around active composting areas, and restriction of windrow turning to times of greatest vertical atmospheric mixing.

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SECTION 3

WINDROW COMPOSTING

FULL-SCALE PLANT OPERATION

Background and Overview

Since 1972 the LACSD have practiced windrow composting of sewage sludge at the JWPCP in Carson, California. For many years prior to 1972, the sludge was simply spread on drying beds for extended periods, after which it was sold to a privately-owned fertilizer company. However, the sludge drying beds required more land area than was available and were a source of offensive odors and vectors. The composting process was adopted in 1972 to minimize this nuisance potential. Composting provided the additional benefits of requiring less land, producing a product that is more uniformly stable, and by producing elevated temperatures significantly reduced pathogenic organism levels. The full-scale composting process at the JWPCP has been modified intermittently since 1972 to incorporate research findings and changes in sludge production and characteristics. The present full-scale windrow composting operation at the JWPCP is described below.

The JWPCP windrow composting process typically utilizes previously composted material ("recycle") as the sole bulking agent. Rice hulls and wood shavings are also being utilized as bulking agents on a small scale because they are being supplied free of charge from the fertilizer company that ultimately receives the finished compost. The recycle of finished compost serves to adjust the moisture content and increase the void space in the mixture, allowing the natural passage of air into the windrows. Anaerobically digested centrifuge-dewatered sludge cake at approximately 23% total solids (TS), is combined in windrows with finished (60% total solids) compost, in a mixture of 0.84 m^3 of finished compost per metric ton of sludge cake (1 yd^3/short ton). Table 1 presents the solids content and bulk density for the finished compost and dewatered sludge cake used for these studies. The windrows are turned by a self-propelled machine designed specifically for this purpose (Figure 1). The machine straddles the windrow, and has a high speed rotating drum at ground level. The drum has flails which lift the sludge up and over the drum, depositing it behind the machine in windrow form. Turning mixes the wet cake and finished compost, increases porosity in the windrow to maintain aerobic conditions, promotes drying of the sludge by exposure to air and sun, and ensures that all of the sludge is subjected to the higher temperatures inside the windrow.

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TABLE 1. BULK DENSITY AND SOLIDS CONTENT OF FINISHED COMPOST AND DEWATERED SLUDGE CAKE

Sludge Type	Total Solids (%)	Bulk Density kg/m^3 (lb/yd^3)
Anaerobically Digested-Centrifuge Dewatered Primary Sludge Cake	22	1045 (1760)
Finished (100% Sludge) Compost	60	800 (1350)
Finished (100% Sludge) Compost	65	710 (1200)
Mixed Compost Material	40-45	880-950 (1485-1600)
Rice Hulls	90	160 (270)
Wood Shavings	90	210 (350)

When the composting sludge has reached at least 60% TS (less than 40% moisture), and the volatile fraction has been reduced to below 40%, the material is dry and stable enough to be used by the fertilizer company. This process takes 4 to 5 weeks during most of the year, except during the winter rains, when the majority of the sludge cake is hauled to a landfill.

Operating Procedure

A schematic diagram of the sludge processing operation is shown in Figure 2. Typically, the centrifuge cake is first conveyed to storage bins, which have a capacity of 5440 wet metric tons (6000 short tons). This capacity allows the sludge to be held for several days during wet weather, if both the compost beds and the landfill are unable to receive sludge. This storage also provides for the transition from the 24 hr dewatering operation to the 10 hr composting operation. From the storage bins, the sludge is conveyed to a truck loading station equipped with weigh bins and then hauled to the composting loading area for treatment or to a landfill for ultimate disposal. The amount of sludge composted is limited by the land area available, the processing time required and, at present, by the amount of odor and dust that may be emitted before it becomes a nuisance.

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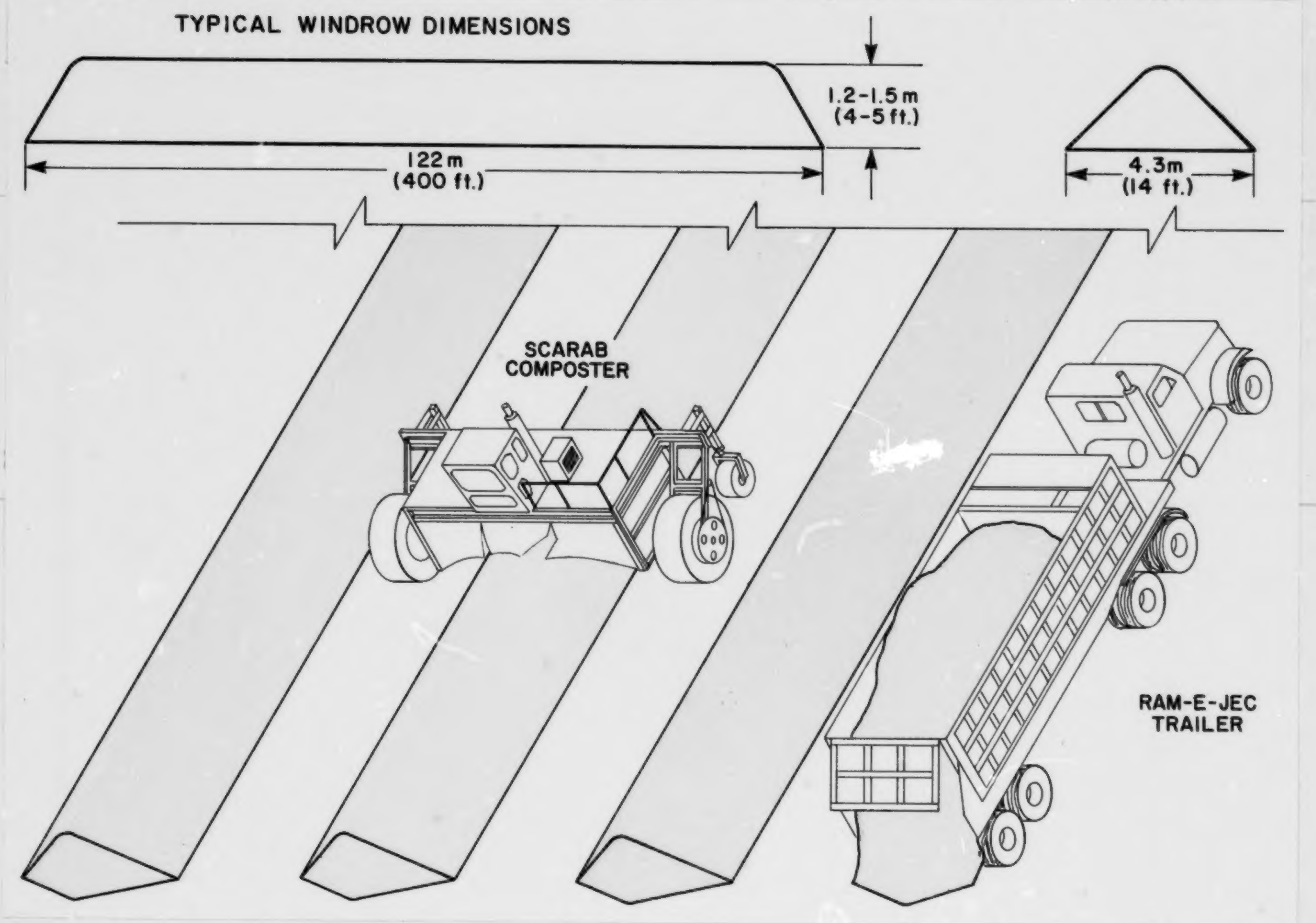
TYPICAL WINDROW DIMENSIONS
1.2-1.5 m
(4-5 ft.)
122 m
(400 ft.)
4.3m
(14 ft.)
SCARAB
COMPOSTER
RAM-E-JEC
TRAILER

Figure 1. JWPCP windrow composting operation.

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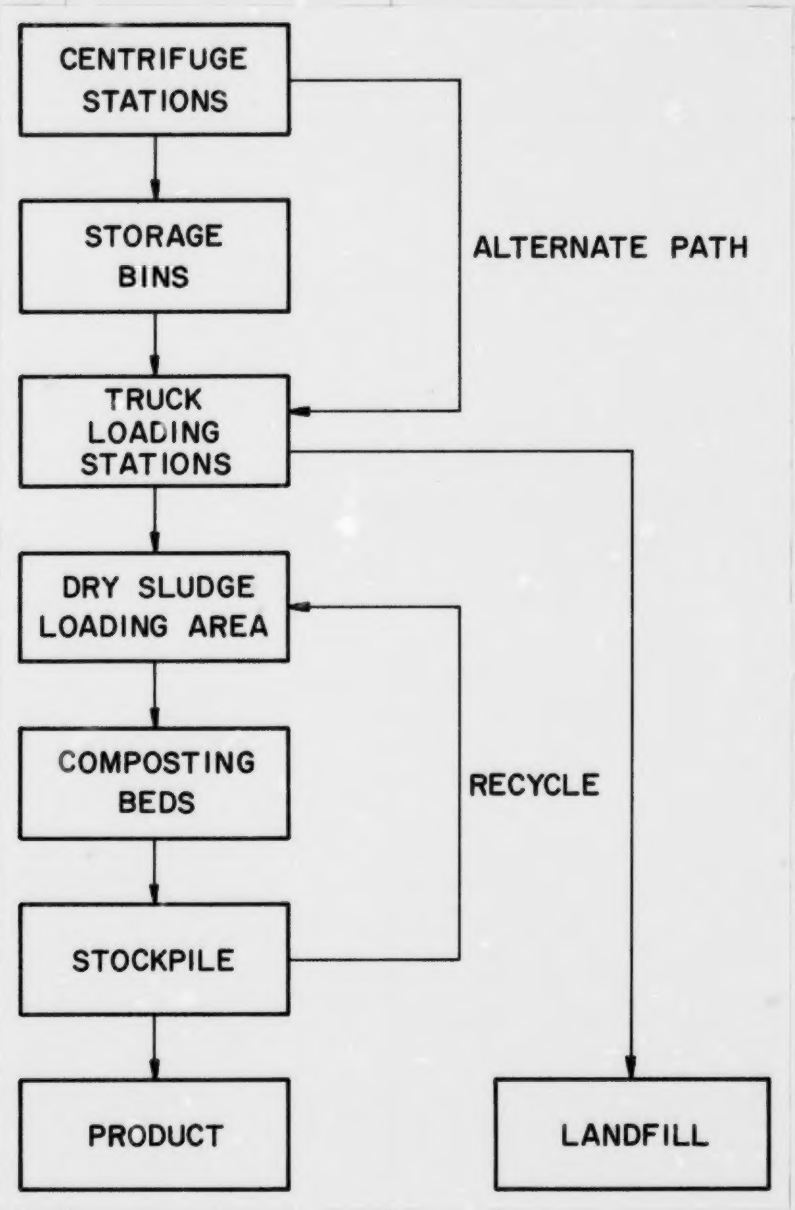
CENTRIFUGE STATIONS
STORAGE BINS
ALTERNATE PATH
TRUCK LOADING STATIONS
DRY SLUDGE LOADING AREA
COMPOSTING BEDS
RECYCLE
STOCKPILE
PRODUCT
LANDFILL

Figure 2. Schematic diagram of the JWPCP sludge processing operation.

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Each truck hauling sludge to the compost beds is loaded with 9 metric tons of wet cake (10 short tons), and then moved to the finished compost loading area where approximately 7.5 m^3 (10 yd^3) of finished material is added from a stockpile. The amount of finished material added is measured by the bucket volume of a front-end loader. The stockpile is constructed on a portion of the compost beds by pushing together several windrows of finished compost. New windrows are placed in the vacated space, and the stockpile is moved down the field as the cycle progresses, minimizing the distance the trucks must travel.

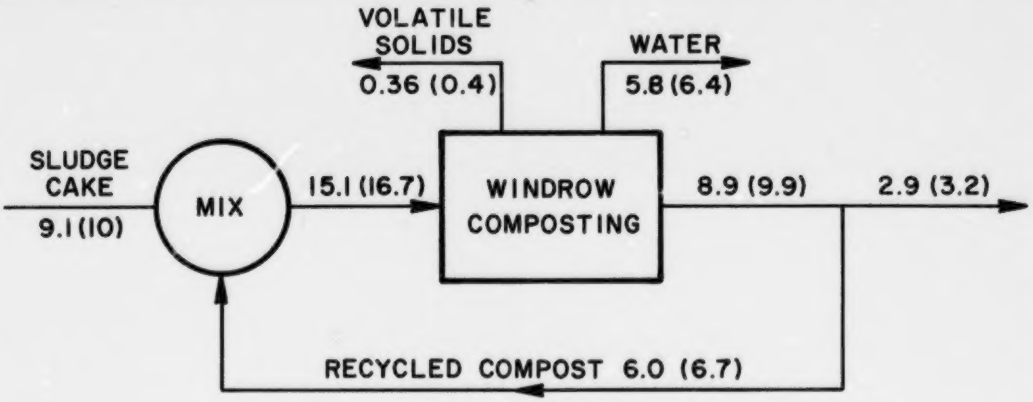
Two types of trailer bodies have been used for construction of the windrows. One type (Flow-Boy) has a chain and flight conveyor running lengthwise in the bottom of a trapezoidal shaped body. Frequent breakdowns have occurred with this type because the flight conveyor contains many moving parts which do not stand up to the abrasive nature of the compost. Also, certain combinations of compost and wet sludge will form a stiff mixture that can bridge over the conveyor, and prevent discharge. A second type (Ram-E-Jec) has been evaluated since early 1980. This Ram-E-Jec has a rectangular body and a full width hydraulic ram to push the sludge. Observed advantages of the latter include greater mechanical reliability, complete discharge of compost material, and a turnaround time (to haul a full load of material to the compost fields and back) of about one-half that for the Flow-Boy trailer, because of faster discharge.

Since combining the wet and dry materials in the trailer provides only limited initial mixing, the present method of constructing a windrow consists of laying two small windrows side-by-side. These windrows are turned and then combined into a single windrow. The dimensions of this windrow are 1.2 to 1.5 m (4 to 5 ft) high and 4.3 m (14 ft) wide. The windrows are turned three times per week to maintain sufficient voids and to allow the natural passage of air into the windrow and to promote drying. A sketch of the composting operation is presented in Figure 1.

The mass balance of the operation (Figure 3) indicates that at the end of the process, the original 9 metric tons (10 short tons) of sludge cake have been converted to approximately 2.9 metric tons (3.2 short tons) of product, with a reduction of one-third its original volume.

The process can produce high levels of odors, particularly in the early part of the cycle, and is likely to generate dust under moderately windy conditions. It is remarkably free of insect and other vector problems.

The finished compost itself is stable and relatively free of odors. The material in excess of that needed for recycle is released to the fertilizer company located immediately adjacent to the plant site. It is then stockpiled until needed, screened, in some cases mixed with other materials, and marketed as a variety of soil amendments.



NOTE: ALL VALUES ARE EXPRESSED IN METRIC TONS (SHORT TONS)

Figure 3. JWPCP windrow composting mass balance.

Land Requirements

Typically, each windrow is constructed from about 30 truckloads of material and is about 150 m (500 ft) long. The windrows are placed on the field at 5.5 m (18 ft) centers, leaving a clear aisle of 1.2 m (4 ft) for the wheels of the turning machines. Each truckload contains 9 wet metric tons (10 short tons) of sludge cake, approximately equivalent to 8.8 m^3 (11.5 yd^3), plus 7.5 m^3 (10 yd^3) of finished compost. Using the criteria described above, it can be estimated that the compost mix is applied to the field at a rate of 0.47 m^3/m^2 (2500 yd^3/acre), or at a rate of 280 wet metric tons/1000 m^2 (1200 short tons/acre) in terms of the sludge cake alone. The amount of land required for composting will be directly proportional to the processing time. Using the application rate defined above and a processing time of 30 days, 9700 m^2 (2.4 acres) would be required for every 90 wet metric tons/day (100 short tons/day) of sludge at approximately 23% solids content. This equates to 38,800 m^2 (9.6 acres) per 90 dry metric tons/day (100 short tons/day) of sludge solids. Additional area must be allotted to the operations of clearing the finished windrows, stockpiling, loading the finished compost into trucks, and for road systems and equipment storage.

A notable feature of the compost beds is that the soil beneath has been treated with lime. The upper 15 to 20 cm (6 to 8 in) of soil are scarified, mixed with lime, and compacted. The resulting surface sheds water, has increased load bearing characteristics, and the 1976 cost was about \$1.00 per m^2 (\$0.10 per ft^2). Although inexpensive, this surface has broken down after several years of intensive use, and asphalt or concrete paving has been recommended for future construction.

Costs

The cost of the composting operation can vary widely depending on the amount of sludge cake which can be composted at any given time. The unit cost per ton of sludge composted is much less from spring through autumn when approximately 450 wet metric tons of sludge cake per day (500 short tons per day) at 23% total solids are processed as compared to the winter application rate of approximately 135 wet metric tons per day (150 short tons per day). These productivities coupled with fixed capital and operating costs result in seasonal costs of approximately \$5.50 per wet metric ton (\$5 per short ton) during most of the year and \$11 per wet metric ton (\$10 per short ton) during the winter months. These costs are for 1983, and they do not include land and overhead costs, such as engineering and support services.

DESCRIPTION OF THE EXPERIMENTAL PROGRAM

Though windrow composting has been practiced at the JWPCP since 1972, the full-scale operation has been intermittently adjusted to meet new conditions. Research in windrow composting has been conducted using the same operational procedure as used for full-scale sludge composting. New composting methods such as aerated static piles have been tested as part of a complete composting research scheme. The composting research and full-scale operation involved three distinct phases to adjust for changes in sludge production and the development of improved composting methods. During each research phase, the major factors influencing the compost operation such as windrow size, turning frequency, percent of recycled finished compost, use of forced aeration, etc., were investigated to upgrade the composting process.

Phase I of the composting research program took place from the beginning of windrow composting in 1972 through December 1976. Prior to 1976, anaerobically digested primary sludge was dewatered by nine medium speed scroll centrifuges operating continuously (without polymer). These centrifuges removed about one-third of the solids from the anaerobically digested sludge, thereby resulting in 90 dry metric tons/day (100 short tons/day) of cake containing approximately 35% TS. The windrows consisted of a 3:1 volumetric mixture of freshly dewatered sludge and finished compost. This mixture had a composite TS content of approximately 40%. Research prior to December 1976 investigated windrow composting of the scroll centrifuge cake which indicated that it could effect excellent microorganism kills. Five windrow research cycles were completed during Phase I operation (Table 2).

Phase II began when a modification to the sludge dewatering process resulted in large increases in sludge production with a corresponding higher moisture content. A second stage centrifuge system composed of 44 basket centrifuges operating on a batch mode (with polymer addition) became operational in December 1976. These basket centrifuges were designed to remove 90% of the solids from the solid bowl centrifuge centrate and produce a sludge cake with 15 to 20% TS. Since the basket centrifuges began

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TABLE 2. WINDROW COMPOSTING CYCLE RESEARCH SUMMARY

Research Phase	Run #	Starting Date	Number of Windrows	Main Parameters Evaluated
1	1	9/11/75	4	turning frequency, climatic effects, VS content
	2	10/20/75	4	" " "
	3	1/21/76	4	" " "
	4	4/12/76	4	" " "
	5	7/28/76	3	" " "
2	6	3/21/77	2	% compost recycle, turning frequency, clumping
	7	4/19/77	2	% basket versus scroll centrifuge cake
	8	5/17/77	2	clumping
	9	8/14/77	4	% compost recycle, odors
	10	10/27/77	3	alternate bulking agents, odors
	11	11/22/77	1	alternate bulking agents, odors
3	12	6/1/78	6	% compost recycle
	13	8/3/78	2	windrow size
	14	10/1/78	2	forced aeration, bacterial odor additives
	15	7/1/79	3	windrow size
	16	7/30/79	4	% compost recycle, windrow size, cycle time, opaque covering
	17	10/13/79	8	windrow size, turning frequency
	18	3/17/80	6	turning frequency
	19	5/28/80	3	alternate bulking agents

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operating, sludge recovery at the JWPCP has increased from 90 to approximately 250 dry metric tons/day (100 to 275 short tons/day). Because the basket cake is wetter than the scroll centrifuge cake, windrows with basket centrifuge cake require greater proportions of finished compost for the 60% moisture needed to initiate composting. The Phase II composting program was conducted from December 1977 through June 1978. During this time period, six windrow research cycles were completed, as noted in Table 2. The results of the research and full-scale operation of the windrow composting process indicated difficulty in achieving successful microorganism kills. Aerated static pile research was also conducted during Phase II.

Phase III began in June 1978 with the discovery that larger windrows produced the temperature elevations needed for acceptable microorganism kills. The earlier tests used shallow windrows of 0.7 to 1.1 m (2.5 to 3.5 ft) high. The larger windrows were 1.2 to 1.5 m (4 to 5 ft) high. Eight windrow cycles were conducted from June 1978 through May 1980 as noted in Table 2. The composting performance was so greatly improved that limited full-scale use of the deep windrows at the JWPCP began about June 1979. At the present time, the whole operation is based on these larger windrows.

A complete presentation of results for all three research phases is presented later in this report.

PARAMETERS FOR THE EVALUATION THE COMPOSTING PROCESS

Various parameters were monitored to evaluate success or failure of the process--temperature elevation, total solids, volatile solids and inactivation of selected microorganisms. Odor emissions were also monitored because of special concerns about the proximity of the surrounding community to the compost fields.

Temperature

Temperature elevation is an extremely important parameter because it is the most direct indicator of whether composting is actually taking place. Composting is an aerobic biological process that generates large amounts of heat through biodegradation of volatile organic matter. The heat is important, because it inactivates pathogens and aids in drying the compost material. Temperatures of 55 to 65°C (131 to 149°F) should be achieved and maintained in the composting material for extended periods. Turning of the windrow insures that all of the compost material will be subject, at some point, to the high internal temperatures. The proposed EPA standards for a proper windrow composting operation are determined according to the number of days at which the windrow temperature is above a given value. The suggested time-temperature requirement for windrow composting is 15 days at or above 55°C (131°F) and a minimum of five turnings during this period.

Total and Volatile Solids

Proper total and volatile solids levels are important in the formation of windrows. These levels also help determine when the composting process is complete. For composting to proceed, windrows should have an initial total solids content of at least 40%, which is achieved by mixing the dewatered cake with previously finished compost material. A total solids content of less than 40% results in a mixture of low porosity which inhibits oxygen transfer within the windrow. The initial volatile solids content of the windrow is about 45 to 50%. It is the destruction of these volatile solids that fuels the composting process. When the volatile solids have been reduced to below 40%, and the total solids have increased to between 60 and 65%, the composting process is completed. The compost material is then stable enough, because of lower moisture and volatile solids concentrations, to be delivered to the fertilizer company for further processing.

Microorganism Inactivation

Most organisms present in raw sewage are concentrated in the sludge produced during standard wastewater treatment processes. Thus, many different types of pathogens are found in the initial composting mixture. Because compost is eventually used as soil conditioner, it is important that pathogenic microorganisms be inactivated. In fact, inactivation of pathogenic microorganisms was the primary goal of the composting research.

Samples were analyzed for indicator microorganisms (total and fecal coliform), enteric pathogenic bacteria (*Salmonella* sp.), parasites (e.g., *Ascaris* sp. ova) and enteric viruses. These microorganisms were selected because of their value as indicator organisms or because they are enteric pathogens known to be present in relatively high numbers.

The bacterial pathogens most commonly associated with sewage are the *Salmonella* and *Shigella* groups. Although some *E. coli* serotypes may be pathogenic under certain conditions, the large number of coliforms excreted with feces are usually not considered a direct public health threat. Coliforms are used as indicators of other more pathogenic enteric bacteria. Similarly, the fecal streptococci, also found in high numbers in feces, are not usually considered pathogenic, but are measured for their indicator value. Salmonellae concentrations in sludge are high enough to be measured directly.

There are many different parasites in sewage and anaerobically digested primary sludge. Among these are the ova of *Ascaris* sp. (human roundworm), *Trichuris trichiura* (Whipworm), *Ancylostoma* sp. and *Necator* sp. (hookworm), and *Hymenolepis* sp. (tapeworm). Distribution of these parasites is affected by geographic factors, but the ova of *Ascaris* is generally found in most locales.

When a human is infected with "worms," it is generally associated with the common intestinal roundworm, *Ascaris* sp. The life cyce begins with the fertilized egg as it passes from the body of the female worm into the fecal material of the infected individual. The female

Ascaris can produce as many as 200,000 eggs per day. The eggs are excreted with the feces from the host and eventually reach the soil. Embryonation occurs after approximately three weeks in a warm moist environment of the soil.

Should the embryonated ova be ingested, the worm will hatch in the intestine and be carried via the bloodstream to the lungs. From the lungs, the worm is coughed and transported up to the trachea, and then swallowed. The adult worm then inhabits the small intestine after completing its development during migration to the lungs and back to the intestine. Passage of migrating larvae through the lungs may cause bronchopneumonia. However, adult worms inhabiting the intestine show no obvious symptoms. Occasionally, the adult worms, which may reach a length of 20 to 35 cm (8 to 14 in) can cause intestinal blockage in heavily infected children. The major concern over this and other human parasites is that children will ingest soil containing quantities of inadequately treated soil amendment manufactured with sludge.

Ascaris ova are highly resistant to chemicals, desiccation, and heat. The fact that they are widespread, highly resistant, and relatively easy to detect in sludge makes their inactivation to low levels a good indicator of successful compost operations.

Another (secondary) pathogenic organism that may be associated with composting is the fungus *Aspergillus*. Aspergilli produce a fungal disease (aspergillosis) with symptoms of acute or chronic inflammatory infection of the lungs, bronchi, sinuses and occasionally other parts of the body. It is usually thought of as a secondary invader since it mainly infects individuals who are suffering from other ailments.

Allergy is the most common complaint associated with aspergilli. Airborne aspergilli spores may cause an allergic reaction resulting in typical rhinitis, conjunctivitis, dermatitis or bronchial asthma symptoms usually associated with allergies. Also, aflatoxins produced by *Aspergillus flavis* may produce a carcinogenic effect (toxicosis), but such cases are usually rare.

Aspergilli are capable of surviving reasonably high temperatures, and high spore concentrations are usually associated with composting vegetable material, wood chip piles, municipal refuse compost and hay. The spores are normally found in the air at relatively low levels ($\sim 500/m^3$) but high concentrations have been detected around compost sites. Compost handling procedures which minimize dust levels and limit the use of organic bulking agents, such as woodchips, straw, husks, etc., can reduce the aspergilli spore concentrations. Determination of the *Aspergillus* spore concentration in the air at compost sites and in adjacent areas may be necessary to determine any possible hazard to the surrounding area. Results of monitoring Aspergilli at JWPCP are described later.

MONITORING AND EXPERIMENTAL TECHNIQUES

Temperature Monitoring

The vast majority of temperature monitoring was conducted using a hand held probe which was inserted into the very center of the windrow at ten points spaced equally distant from each other along the length of the windrow. Windrow temperatures in this report are an arithmetic mean of these values. During Phase I, temperatures were recorded automatically using temperature probes which were inserted in three positions along the windrow. Each temperature probe contained three thermocouples spaced equally distant along the probe.

Total and Volatile Solids

Total and volatile solids data were collected in the following manner. Immediately after the windrow was turned, samples were taken from the exterior of the pile at different points along its length. The turning machine produces a very uniform moisture after the windrow is turned. An average of these samples yields an accurate value for the solids content of the windrows. The procedure for analyzing the solids samples was taken from *Standard Methods* (2).

Microorganism Inactivation

Sampling for microorganism analyses was similar to solids sampling and special care was taken to obtain an uncontaminated sample. Plastic bags were first turned inside out and the sample was then taken by placing the hands inside the bag, grabbing the sample and reversing the bag.

Multiple tube fermentation tests for total and fecal coliforms were performed as described in *Standard Methods*. Samples were prepared for inoculation by suspending a predetermined amount of compost, on a weight-volume basis, in a phosphate buffered saline solution containing 0.1% Tween 80. The suspensions were blended for 1 min in a Waring blender immediately prior to inoculation. The sample-diluent ratio most commonly used was 10 g sample/ 100 ml diluent. Results are reported as concentration per gram of solids.

Samples which were tested for salmonellae were prepared as described above. The sample suspension was inoculated into tetrathionate broth (Difco) in a multiple tube dilution pattern. After 18-24 hr incubation at 37°C, the tetrathionate enrichment cultures were streaked to XLD agar (Difco) and bismuth sulfite agar (Difco) and again incubated for 18-24 hours at 37°C. The plates were examined for colonies exhibiting typical *Salmonella* sp. morphology; representative colonies were picked and stabbed into TSI slants (Difco) and LIA (Difco) and incubated for 18-24 hrs at 37°C. Isolates producing reactions typical for *Salmonella* sp. were confirmed by agglutination with polyvalent O antisera (A-I and Vi, Difco). Tetrathionate tubes which were confirmed to contain salmonellae were used to compute the *Salmonella* sp. titer from standard MPN tables.

The analysis for Ascaris involves a three part procedure consisting of separation and concentration of the ova, viability testing, and quantitation. Compost samples were suspended in phosphate buffered saline with 0.1% Tween 80 as previously described for the bacterial tests. A measured amount of suspension, usually 400-500 ml, was washed through a 40 mesh sieve with warm water into a tall beaker and the suspended particles were left to settle over night. After settling, the supernatant was vacuum decanted and the settled material, which contains the ova, was centrifuged at 1500 rpm for 3 min. The resulting supernatant was discarded and the remaining solids were resuspended in a $ZnSO_4$ solution (specific gravity 1.18). The resulting mixture was again centrifuged at 1500 rpm for 6 min. The $ZnSO_4$ supernatant, containing the ova, was vacuum filtered through a 5 micron porosity membrane. The material collected on the filter surface was washed off with 0.1 N H_2SO_4 into a 16 x 100 mm polypropylene culture tube and capped.

The ova recovered in the concentrate were incubated at 28°C for approximately four weeks and then microscopically examined for embryonation. The ability to embryonate was used as the measure of viability and potential infectivity. The sample was placed in a Sedgwick Rafter cell for microscopic examination and enumeration. A denotation of (<) indicates that no viable ova were detected (sample below detection limits of the procedure). The corresponding number is the detection limit, which is a function of the test procedure. Final concentrations of total and viable ova were calculated according to the formula:

$$\text{Ova/g solids} = \frac{A \times B \times \frac{K}{n}}{W}$$

where:
A = number of ova counted
B = ml of final concentrate
K = Sedgwick Rafter cell constant
n = number of transects
w = g dry solids in original sample screened

An alternate method of determining ova viability using a dye stain was developed and adopted in mid 1976 and used through 1978. Subsequent problems with different dye lots raised questions about some of the results. These data, therefore, have not been included in this report.

Samples analyzed for thermotolerant aspergilli were processed and blended as previously described for the bacterial tests. Appropriate dilutions of sample suspension were inoculated onto the surface of Littman Oxgall agar containing 30 micrograms of streptomycin per ml of medium. The inoculations were spread evenly on the surface of the agar and the plates were incubated in a humidified chamber at 44°C for 48 hrs. Colonies exhibiting Aspergillus sp. morphology were counted and the colony forming units (CFU) per gram of solids were calculated.

The fate of human enteric viruses in sludge was considered an important aspect of the microorganism inactivation studies. No standard laboratory methods existed, however, to deal with the virus question. Development of virus techniques for compost and the subsequent testing became a project in itself. A thorough review of the virus problem and results of this study are reported separately in the Appendix of this report.

Odors

Odor emissions were also monitored periodically throughout the composting research program. Samples were collected by placing a 1 ft^3 box, open at one end, directly on top of the windrow with the open end down. By pumping carbon-filtered ambient air at a rate of 0.17 ft^3/min into the side of the box, a sample was collected at the opposite end of the box. Internal baffles were utilized to minimize short circuiting of odor free air from one end of the box to the other.

The odor level of a given sample is determined by progressively diluting the initial sample. The diluted samples are then judged by a panel of 5-10 people. This method, often referred to as the sniff technique, is the American Standard for Testing Materials procedure for measuring relative odor levels.* The odor level of a given sample is defined as the number of dilutions with odor-free air necessary to teach the threshold of detection (this is referred to as the odorous dilution ratio). For reference, an odor level or ratio of 1 is just barely detectable while an odor ratio of 50 is a moderate odor. Odor levels or ratios in excess of 100 are considered very strong.

Odor emissions were calculated by multiplying the air flow rate at which a particular sample was collected, 0.17 ft^3/min, by the odor level of the sample with a resulting odorous emission rate in units of ft^3/min. Since the area being sampled was one square foot, odor emissions are on a per square foot of windrow surface basis ($ft^3/min/ft^2$).

PHASE I RESULTS

The overall purpose of the windrow composting research has been to vary different operational parameters to optimize performance. Phase I studies focused on the influence of turning frequency, cycle time, recycle ratio, and recycle material. A review of these parameters and overall research results is presented in the next three sections.

Phase I operation was conducted from 1972 through December 1976 and only the medium speed scroll centrifuges were operated for sludge dewatering. These scroll centrifuges recovered about one-third of the anaerobically digested solids and produced a 35% TS cake. Phase I research on microorganism survival began in mid 1975. Minimizing the processing time while meeting the microorganism inactivation objectives was the principal goal of the Phase I studies. Because of the introductory nature of Phase I results, general observations on windrow temperature, moisture content and volatile solids destruction are included along with a discussion of the factors affecting windrow performance such as turning frequency, climate, etc.

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* American Standard for Testing Materials, Annual Book of ASTM Standards, Part 26, 470-473, Philadelphia, PA, 1981.

Temperature

Because temperature is important for microorganism inactivation, emphasis was placed on the measurement of temperature inside the windrows. Temperatures for Phase I were monitored and recorded automatically at 30 min. intervals using thermocouples placed in three positions inside the windrow. The temperature was measured at each of the three points and the results averaged.

Temperature data are summarized in Table 3, which includes maximum temperatures attained and the period of time that temperatures above 60°C (140°F) were sustained. Maximum temperatures observed during winter compost cycles were 55 to 60°C (131 to 140°F), whereas maximum temperatures observed in late fall, spring and summer compost cycles were from 60 to 70°C (140 to 158°F). These seasonal temperature variations are attributed to higher ambient temperatures and lack of rain during fall, spring and summer periods. Whenever compost cycles were completed without composter failure or heavy rains, temperatures above 60°C (140°F) were achieved for approximately 15 to 25 days.

Compost pile turning frequencies of 1 turn every 3 days to 3 turns per day were evaluated to determine which frequency produced the highest internal windrow temperature and the shortest drying time. Operational modes in which the material was turned less than once per day (processing modes 4 and 6 - Table 3) produced the least number of consecutive days where temperatures exceeded 60°C (140°F). Increasing the turning frequency to one turn per day produced longer periods of temperatures greater than or equal to 60°C (140°F). (However, in Phase II, windrows with only 3 turns per week produced longer periods of higher temperature than those turned once per day). These longer periods of elevated temperatures, however, may not be necessary to ensure adequate microorganism kills; less frequent turning frequencies may be desirable. Increasing the frequency to greater than one turn per day did not appear to cause further changes in maximum temperature or duration of elevated temperatures.

Total and Volatile Solids

Because moisture affects drying time and, therefore, the area required for composting, moisture content of the material throughout the composting cycle is a very important design parameter. The number of days to reach a TS content of 60% is listed for each composting cycle in Table 4. A total solids content of 60% was chosen for comparison because at this level, the material is suitable for efficient handling by the fertilizer company, and because microorganism activity is severely hindered above 60% TS. Comparatively little activity occurs above 80% TS. In the absence of heavy rains or composter breakdown, operational modes in which the compost material was turned at least once per day produced material with 60% TS in

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TABLE 3. SUMMARY OF TEMPERATURE DATA FOR PHASE I WINDROW CYCLES

Run #	Processing Mode[a]	Maximum Temperature °C (°F)	Days >60°C	Comments
1	1	65 (149)	10	Composter down approximately 5 days
	2	65 (149)	20	
	3	65 (149)	14	
	4	65 (149)	7	
2	1	61 (142)	2	Composter down approximately 15 days
	2	59 (138)	1	
	3	61 (142)	2	
	4	61 (142)	1	
3	1	57 (135)	0	Heavy rain and composter failure
	2	54 (129)	0	
	5	58 (136)	0	
	6	57 (135)	0	
4	1	64 (147)	17	Composter operation reliable
	5	62 (144)	14	
	6	61 (142)	7	
	7	64 (147)	15	
5	1	70 (158)	31	
	2	- --	-	
	3	70 (158)	24	

[a] Processing modes -

1 = one turn/day
2 = two turns*/day
3 = three turns*/day
4 = one turn/two days
5 = two turns°/day for 1st 10 days, one turn/day thereafter
6 = one turn/three days
7 = two turns°/day

* Consecutive turns °Non consecutive turns

about 20 to 35 days. This is in contrast to Run 3 where rain and composter failure necessitated 55 to 75 days of composting to reach 60% TS. Turning frequencies of less than once per day produced a 60% TS conpost in 30 to 40 days under good conditions and 45 to 65 days when heavy rains and/or composter failure occurred.

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Because destruction of VS occurs during composting, VS content has been used as an index of compost stabilization. As indicated in Table 4, VS content of the centrifuge cake is reduced 10 to 15 percentage points during the compost cycle. Each of the processing modes produced a final compost VS content of about 35 to 40%.

TABLE 4. SUMMARY OF TOTAL AND VOLATILE SOLIDS CONTENT FOR PHASE I WINDROW CYCLES

Run #	Processing Mode*	Initial TS Content, %	Days to Reach 60% TS	Initial VS Content, %	Days to Reach 40% VS	Final Compost VS,%
1	1	35	>35	50	27	37
	2	35	>35	53	29	37
	3	37	25	53	29	37
	4	35	30	50	28	39
2	1	37	44	47	27	37
	2	33	31	48	25	36
	3	35	35	47	25	36
	4	37	45	47	29	38
3	1	32	67	53	24	34
	2	32	56	52	27	33
	5	35	58	50	35	37
	6	33	>68	52	27	35
4	1	35	33	50	19	37
	5	34	29	49	20	37
	6	35	36	48	20	35
	7	36	30	48	22	35
5	1	32	23	50	35	40
	2	36	17	50	17	38
	3	38	13	-	16	41

* See footnote on Table 3

Microorganism Inactivation

Three major groups of microorganisms were analyzed in the compost sludge samples during Phase I: parasites, bacteria and viruses. Interior and exterior samples were collected about twice per week. Ascaris sp. ova were detected consistently during each of the Phase I compost cycles. However, viable ova were seldom detected near the end of the compost cycle. Representative results for the presence of Ascaris sp. ova in Run 5 are presented in Table 5.

Table 6 contains a summary of total coliform data. Initial total coliform counts in compost material are typically 1.0 x 10^7 to 5.0 x 10^8 MPN/g solids (dry weight basis). Total coliform numbers were often reduced four to five logs during the first 10 days of composting. Final interior total coliform concentrations were typically less than 2 MPN/g in spring and summer months, but were 10^3 MPN/g in winter months.

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Regrowth of coliforms in the exterior of the compost windrows may have taken place as shown by the slightly higher exterior final coliform concentrations in Table 6. During October and November 1976, laboratory experiments were conducted to determine the amount of bacterial regrowth during sludge composting. Compost samples were divided into two aliquots, one of which was analyzed immediately for total coliform, fecal coliform, and salmonellae. The second aliquot of each sample was incubated for 30 days at 30°C (86°F) and subsequently analyzed.

Of twelve samples, significant coliform regrowth occurred in three, and in only one of these three samples was the total coliform regrowth accompanied by regrowth of fecal coliform and *Salmonella* sp. Regrowth may have been inhibited by the dryness or available nutrients of the composted material. Based on the results of these experiments, it does not appear that regrowth under good composting conditions would result in high levels of bacterial contamination in bagged fertilizer. This subject, however, was addressed in greater detail later in the project.

Salmonellae assays were performed less frequently than coliform assays. A comparison of Tables 6 and 7 indicate that the time required to reach minimum coliform concentration in each of the runs was in most cases either the same as or greater than the time required to reach the minimum *Salmonella* sp. concentration. The salmonellae reached their detection level more consistently than the coliforms.

TABLE 5. REPRESENTATIVE RESULTS FOR THE PRESENCE OF *ASCARIS* SP. OVA DURING PHASE I

Run #	Processing Mode*	Days of Composting	*Ascaris* sp. Concentration ova/g: Interior Total	Sample Viable	Exterior Total	Sample Viable
5	1	0	104	12	45	0
		5	48	14	53	0
		12	21	0	12	0
		19	10	0	18	0
		28	7	0	11	0
		33	22	0	39	0
	2	0	65	0	154	63
		7	61	0	52	7
		14	5	0	12	0
		21	20	0	10	0
		30	20	0	21	0
	3	0	53	10	62	10
		8	26	0	19	0
		15	25	1	16	0
		25	8	0	8	1

* See Footnote on Table 3

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TABLE 6. SUMMARY OF TOTAL COLIFORM DATA FOR PHASE I WINDROW CYCLES

Run	Processing*	Initial Total Coliform Concentration		Lowest Total Coliform Concentration				Final Total Coliform Concentration		
#	Mode	Interior MPN/g	Exterior MPN/g	Interior MPN/g	day	Exterior MPN/g	day	Interior MPN/g	Exterior MPN/g	day
1	1	1.0×10^{8}	1.0×10^{8}	<0.6	33	0.7	33	<0.6	0.7	33
	2	4.8×10^{10}	9.3×10^{8}	2	32	5.1×10^{3}	32	2	5.1×10^{3}	33
	3	4.3×10^{8}	9.9×10^{8}	11	19	2.5×10^{4}	30	63	2.5×10^{4}	33
	4	1.3×10^{7}	1.3×10^{7}	<0.7	33	<0.6	33	<0.7	<0.6	33
2	1	2.3×10^{7}	--	<0.6	43	290	43	<0.6	290	51
	2	2.3×10^{7}	--	2.3×10^{3}	20	9.7×10^{2}	20	4.3×10^{3}	$\geq 4.3 \times 10^{4}$	42
	3	4.3×10^{8}	1.1×10^{10}	10	28	220	28	1.7×10^{3}	4.4×10^{4}	43
	4	4.4×10^{6}	--	3	40	4	40	9.4×10^{2}	3.0×10^{5}	46
3	1	4.4×10^{8}	--	<9	54	4.9×10^{2}	54	4.9×10^{4}	8.9×10^{3}	68
	2	2.2×10^{6}	--	66	13	5.2×10^{2}	58	4.9×10^{3}	1.6×10^{4}	69
	5	2.3×10^{8}	--	3.7×10^{2}	55	4.4×10^{2}	63	4.6×10^{3}	4.3×10^{5}	67
	6	2.3×10^{4}	--	4	55	9.3×10^{2}	65	5.4×10^{2}	9.8×10^{4}	69
4	1	6.2×10^{7}	--	<0.6	35	<0.6	35	0.8	4	42
	5	3.5×10^{6}	1.6×10^{7}	<0.6	38	<0.6	38	<0.6	<0.6	42
	6	1.4×10^{7}	3.0×10^{8}	<0.6	42	2	32	<0.6	9	38
	7	N.S.	--	<0.6	29	2	32	2	17	36
5	1	4.5×10^{7}	4.3×10^{7}	<2	35	<2	35	<2	<2	35
	2	3.6×10^{8}	1.3×10^{9}	2	28	<2	30	<2	<2	35
	3	2.1×10^{7}	8.4×10^{6}	<0.2	31	0.3	31	<2	18	33

* See footnote on Table 3

Interpreting the significance of salmonellae data is often difficult because some controversy exists concerning the minimum infective dose of *Salmonella* in humans. Infective dose is the number of bacterial cells required to initiate an infection in an individual. Traditionally, reports have indicated the infective dose of salmonellae to be generally quite high, i.e., on the order of magnitude of 10^4 - 10^5 cells. More recent information indicated that infective dose may be as low as 1-100 cells (3, 4). The final *Salmonella* sp. concentrations of Phase I, however, do not appear to impose any significant health implications.

During the first two compost cycles viruses were isolated in samples collected after 6 days of composting in mode four, 21 days in mode one, and 19 days in mode three. No viruses were detected in the final compost material in any of the four operational modes utilized in the first two compost cycles. Samples of centrifuge cake assayed for viruses during Run 3 did not reveal the presence of viruses and it was concluded that additional work was needed on the methods of virus isolation. Samples taken from later composting cycles were frozen to wait development of improved assay techniques. As previously mentioned, the results of the subsequent virus studies are summarized in the Appendix.

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TABLE 7. SUMMARY OF SALMONELLAE DATA FOR PHASE I WINDROW CYCLES

Run	Processing*	Initial Salmonellae Concentration		Lowest Salmonellae Concentration				Final Salmonellae Concentration		
#	Mode	Interior MPN/g	Exterior MPN/g	Interior MPN/g	day	Exterior MPN/g	day	Interior MPN/g	Exterior MPN/g	day
1	1	2.0×10^{6}	2.0×10^{6}	<0.2	33	<0.2	33	<0.2	<0.2	33
	2	2.0×10^{6}	2.0×10^{6}	<0.2	32	6.2	32	<0.2	6.2	33
	3	2.6×10^{5}	2.6×10^{5}	<0.3	19	4.2×10^{2}	30	<0.3	4.2×10^{2}	33
	4	9.8×10^{5}	9.8×10^{5}	<0.3	33	<0.2	33	<0.3	0.2	33
2	1	4.4×10^{3}	--	<0.2	39	<0.2	39	<0.2	<0.2	51
	2	6.7×10^{3}	--	2.2	13	27	33	4.4×10^{2}	27	42
	3	1.2×10^{3}	2.4×10^{5}	<0.2	28	<0.2	28	17	0.2	43
	4	1.4×10^{4}	--	<0.2	40	<0.2	40	<0.2	3.0×10^{2}	46
3	1	9.5×10^{5}	--	<0.3	54	0.8	54	0.8	<0.2	68
	2	2.7×10^{4}	--	<0.2	69	<0.2	69	<0.2	<0.2	69
	5	8.8×10^{5}	1.7×10^{5}	<0.2	60	<0.2	60	0.2	<0.2	67
	6	8.8×10^{5}	--	<0.2	65	<0.2	65	<0.2	<0.2	69
4	1	4.3×10^{3}	--	<0.2	21	<0.2	21	<0.2	<0.2	42
	5	--	--	<0.2	38	<0.2	38	<0.2	<0.2	42
	6	6.7×10^{3}	--	<0.2	28	<0.2	28	<0.2	<0.2	38
	7	24	28	0.2	29	<0.2	32	<0.2	<0.2	36
5	1	$<3\times10^{3}$	9.3×10^{4}	<0.07	33	<0.07	28	<0.07	<0.07	35
	2	1.4×10^{6}	1.6×10^{7}	<0.07	28	<0.07	30	<0.07	<0.07	35
	3	2.1×10^{4}	1.4×10^{4}	<0.07	31	<0.06	31	<0.08	0.3	33

* See footnote on Table 3.

Summary

The influence of climate, turning frequency, and volatile solids content on the ability of composting to produce high temperatures was studied during Phase I. In the absence of rain and composter apparatus breakdown, temperatures as high as 60 to 65°C (140 to 149°F) were produced when initial volatile solids composed about 50% of the dry weight. Low ambient temperatures, rainfall, and composter malfunctions caused temperatures in the interior of the compost windrows to peak at about 55 to 60°C (131 to 140°F).

Human parasitic ova were monitored and intact _Ascaris_ sp., _Trichuris trichiura_, and hookworm ova have been isolated during the compost cycles. _Viable Ascaris_ sp. ova were rarely found late in the compost cycles, except when maximum windrow temperatures were below 60°C (140°F). In these cases, viable ova were found throughout the cycle. Total coliform and _Salmonella_ sp. concentrations rapidly decreased within the first 10 days of composting. In addition, final coliform concentrations of less than 2 MPN/g were achieved in interior samples of warm weather compost cycles, and final salmonellae concentrations of less than 0.2 MPN/g were achieved in both interior and exterior samples collected during warm months. Some bacterial regrowth was observed in all cycles, predominantly in samples from windrow exteriors, but was considered insignificant during periods of no rainfall.

PHASE II RESULTS

Phase II studies began in December 1976 after the startup of basket centrifuges significantly increased the recovery of dewatered anaerobically digested sludge solids (see windrow runs 6 through 11, Table 2). The basket centrifuges were initially operated in series with the scroll centrifuges (parallel operation began in March 1978) treating the scroll centrifuge centrate which contained the finer sludge solids. The basket centrifuges were operated using polymer conditioning and recovered in excess of 90% of the incoming solids, yielding dewatered sludge cakes of about 18% TS. Thus, the new combined cake consistency changed from 35% TS (for the scroll centrifuge cake only) to 20 to 25% TS in the combined cake, causing immediate hindrances to the full-scale composting operation. To start the windrows at the same initial TS content (40% TS), more bulking agent (recycled finished compost) had to be used. This not only increased the amount of land area required but resulted in other problems such as clumping of the compost solids, inadequate temperature elevations, and ultimately poor pathogen inactivation.

This section of the report discusses the research on windrow composting of the two-stage dewatered sewage sludge from March 1977 through November 1977. The main objectives of the research were to determine what parameters most affected the composting process and to investigate the problems encountered with composting of the two-stage centrifuge cake versus composting of the scroll centrifuge cake alone. Several composting cycles with varying mixture ratios of finished compost to sludge were tested.

Windrow Runs 6 through 11

Run 6 consisted of two windrows which were constructed using a basket to scroll centrifuge cake ratio of 1:1 (dry solids basis) and a mixture ratio of 0.84 m^3 per metric ton (1 yd^3/short ton) of finished compost to sludge cake, respectively. Table 8 contains a summary of the experimental conditions for the research compost cycles during Phase II. Turning frequencies were one turn per day for Windrow 1 and two (non-consecutive) turns per day for Windrow 2.

Windrow 2 was turned in the early morning and late afternoon hours of each day of the compost cycle. The main objective of run 6 was to determine what effect varying the turning frequency would have in a windrow compost cycle using combined centrifuge cakes. Previous research indicated that a turning frequency of once per day yielded optimum temperature elevations while keeping the drying time to a minimum.

The data for all Phase II runs are shown in Tables 9 through 14. Temperature elevations plotted against time into the compost cycle for Run 6 appear in Figure 4. Temperature elevations were poor throughout the cycle and very little inactivation of coliforms occurred. High levels of *Salmonella* sp. and viable *Ascaris* sp. ova were detected in both the interior and exterior final samples of both windrows. Initial volatile solids contents of both rows were somewhat low since a greater amount of

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TABLE 8. SUMMARY OF EXPERIMENTAL CONDITIONS FOR PHASE II WINDROW CYCLES

Run #	Windrow #	Mixture Ratio* Finished Compost: Sludge Cake m^3/metric ton (yd^3/short ton)	Dewatered Cake Composition Basket:Scroll Centrifuge Cake (dry weight basis)	Turning Frequency	Comments
6	1 2	0.84:1 (1:1) 0.84:1 (1:1)	1:1 1:1	1/day 2/day	Windrow 2 received two non-consecutive turns per day-one in the A.M. and one in the P.M.
7	1 2	0.84:1 (1:1) 0.84:1 (1:1)	1.5:1 1.5:1	1/day 1/day	Micro samples taken after turning Windrow 1 and before turning of Windrow 2 to determine amount of regrowth on the exterior of the row.
8	1	0.84:1 (1:1) 100% cake	2:1 2:1	1/day 1/day	Windrow 2 consisted of three windrows of 100% cake which were combined after 24 days to form one windrow.
9	1 2a,b 3	0.84:1 (1:1) 0.42:1 (0.5:1) 100% cake	2.1:1 2.1:1 2.1:1	1/day 1/day 1/day	Two windrows were laid using the Windrow 2 mixtures and three windrows were laid using the Windrow 3 mixture. Windrow 3 rows were combined after 22 days while the two rows of Windrow 2 mixtures were not combined and shall be referred to as 2a and 2b.
10	1 2 3	0.84:1 (1:1) see text see text	0.9:1 0.9:1 0.9:1	1/day 1/day 1/day	Windrows 2 and 3 utilized rice hulls and redwood shavings, respectively, as bulking agents.
11	1	see text	1.3:1	1/day	Shredded tree trimmings used as bulking agent.

* Total solids contents of the cake and dry compost averaged 25% and 65%, respectively, and the bulk densities for the two were assumed to be 1045 kg/m^3 (1760 lb/yd^3) and 800 kg/m^3 (1350 lb/yd^3), respectively.

recycle material was added to compensate for the extra moisture in the two-stage sludge cake. It was observed early in the compost cycle that the texture of both rows was much different than those constructed with only scroll centrifuge cake. Large clumps were formed and the mixture appeared to have a consistency similar to clay. The size of these clumps varied from very tiny marble size up to 8 to 13 cm (3 to 5 in) in diameter. This clumping phenomenon continued until the end of the cycle. It was theorized that clumping may be due to the mixing of larger amounts of dry material with the wet cake and the use of polymer in the basket centrifuges.

Run 7 was a duplicate of Run 6 except that the turning frequencies were once/day for both rows, since varying the turning frequency seemed to have no effect on either temperature elevation or drying time for Run 6. The composition of the cake was changed to a ratio of 1.5:1 of basket to scroll centrifuge cake. In run 7, microbiological samples were taken immediately after Windrow 1 was turned and before Windrow 2 was turned to quantify what coliform regrowth, if any, was taking place because of very low (ambient) temperatures on the exterior of the windrows. Initial TS and VS content were identical to Run 6, but much better temperature elevations

TABLE 9. SUMMARY OF TOTAL AND VOLATILE SOLIDS CONTENT FOR PHASE II WINDROW CYCLES

Run #	Windrow #	Duration of Cycle (days)	Time to Reach 60% TS (days)	TOTAL SOLIDS %			VOLATILE SOLIDS %			
				Start of Cycle	Midway Through Cycle	End of Cycle	Start of Cycle	Midway Through Cycle	End of Cycle	Reduction in VS %
6	1	26	21	39.8	55.7	66.0	44.8	41.7	33.5	25.2
	2	26	24	44.6	55.8	63.1	40.8	----	34.6	15.1
7*	1	25	18	42.3	54.0	59.9	43.1	39.7	36.7	14.8
	2	25	14	41.8	55.8	62.1	43.3	38.0	35.4	18.2
8	1	33	18	45.9	54.8	64.5	41.1	37.5	37.5	8.7
	2**	40	--	23.6	39.9	55.7	52.1	48.2	42.9	17.6
9	1	37	25	36.4	52.7	69.2	47.9	39.1	37.2	22.3
	2a	37	25	35.4	47.8	66.3	48.1	42.0	37.0	23.1
	2b	37	25	34.3	51.1	69.7	48.3	36.7	33.6	30.4
	3**	32	28	25.0	37.6	63.9	55.0	42.1	36.9	32.9
10	1	22	18	43.6	54.7	65.1	45.2	40.9	39.2	13.2
	2	22	8	53.5	63.1	70.4	53.2	43.0	43.9	17.4
	3	22	18	46.5	54.0	60.3	55.4	51.1	48.7	17.0
11	1	20	--	49.0	51.3	59.8	42.5	40.3	41.1	3.3

* 5.9 cm(2.3 in) of rain fell on days 19, 20, and 21.

** The numbers presented here are the average values for various windrows which were tested using the same initial conditions (see Table 8).

TABLE 10. SUMMARY OF INTERNAL WINDROW TEMPERATURE DATA FOR PHASE II WINDROW CYCLES

Run #	Windrow #	Duration of cycle (days)	Maximum Average Daily Temperature °C (°F)	Time (days) to Reach Average Daily Temperatures			Time (days) Average Daily Temperatures Exceeded		
				50°C (122°F)	55°C (131°F)	60°C (140°F)	50°C (122°F)	55°C (131°F)	60°C (140°F)
6	1	26	53 (127)	19	--	--	1	0	0
	2	26	59 (138)	24	--	--	1	0	0
7	1	25	61 (142)	5	7	7	10	3	1
	2	25	56 (133)	11	16	--	5	2	0
8	1	33	54 (129)	14	--	--	8	0	0
	2*	40	72 (162)	13	13	18	14	11	3
9	1	37	59 (138)	12	15	--	26	9	0
	2a	37	60 (140)	16	17	21	14	15	0
	2b	37	61 (142)	16	20	20	[illegible]	3	1
	3*	32	67 (153)	25	25	25	25	9	6
10	1	22	54 (129)	5	--	--	6	0	0
	2	22	60 (140)	4	4	4	13	9	0
	3	22	59 (138)	4	4	--	9	7	0
11	1	20	53 (127)	10	--	--	4	0	0

* The numbers presented here are the average values for the various windrows which were tested using the same initial conditions (see Table 8).

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TABLE 11. SUMMARY OF TOTAL COLIFORM DATA FOR PHASE II WINDROW CYCLES

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Run #	Windrow #	Initial Total Coliform Concentration MPN/g		Lowest Total Coliform Concentration MPN/g				Final Total Coliform Concentration MPN/g			
		Interior	Exterior	Interior	Day	Exterior	Day	Interior	Day	Exterior	Day
6	1	$3.0x10^{7}$	$1.8x10^{7}$	$2.5x10^{5}$	22	$8.1x10^{5}$	25	$8.1x10^{5}$	25	$8.1x10^{5}$	25
	2	$6.8x10^{6}$	$3.1x10^{6}$	$2.5x10^{5}$	25	$2.7x10^{5}$	22	$2.5x10^{5}$	25	$1.2x10^{6}$	25
7	1	$2.8x10^{8}$	$3.5x10^{6}$	0.6	16	0.6	16	$8.3x10^{6}$	24	$7.7x10^{4}$	24
	2	$4.7x10^{7}$	$6.2x10^{9}$	1.4	16	0.6	16	$3.8x10^{1}$	24	$6.9x10^{4}$	24
8	1	$7.6x10^{7}$	$1.3x10^{8}$	4	30	40	30	4	30	40	30
	2*	$2.4x10^{7}$	----	1.4	39	8.6	39	1.4	39	8.6	39
9	1	$3.6x10^{6}$	$3.6x10^{7}$	2	19	$1.2x10^{2}$	30	$7.7x10^{3}$	37	$4.0x10^{2}$	37
	2a	$7.2x10^{6}$	$1.1x10^{7}$	<0.4	30	6	30	$8.3x10^{2}$	37	$8.3x10^{2}$	37
	2b	$7.2x10^{6}$	$1.8x10^{6}$	8	37	$1.3x10^{2}$	33	8	37	$4.3x10^{2}$	37
	3*	$5.1x10^{6}$	$8.7x10^{6}$	$1.2x10^{2}$	40	$1.3x10^{2}$	40	$1.2x10^{2}$	40	$1.3x10^{3}$	40
10	1	$1.4x10^{8}$	$1.4x10^{8}$	$2.4x10^{1}$	11	$1.8x10^{3}$	11	$3.9x10^{5}$	22	$6.4x10^{3}$	22
	2	$5.8x10^{8}$	$5.8x10^{8}$	$5.4x10^{2}$	11	$2.3x10^{4}$	18	$3.6x10^{5}$	22	$3.6x10^{5}$	22
	3	$7.2x10^{8}$	$7.2x10^{8}$	$2.8x10^{1}$	11	$2.6x10^{3}$	11	$7.9x10^{5}$	22	$\geq 3.6x10^{6}$	22
11	1	$1.3x10^{9}$	----	$2.0x10^{7}$	20	$1.9x10^{7}$	20	$2.0x10^{7}$	20	$1.9x10^{7}$	20

* The numbers presented here are the average values for the various windrows which were tested using the same initial conditions (see Table 8)

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TABLE 12. SUMMARY OF FECAL COLIFORM DATA FOR PHASE II WINDROW CYCLES

Run #	Windrow #	Initial Fecal Coliform Concentration MPN/g		Lowest Fecal Coliform Concentration MPN/g				Final Fecal Coliform Concentration MPN/g			
		Interior	Exterior	Interior	Day	Exterior	Day	Interior	Day	Exterior	Day
6	1	$3.0x10^{6}$	$3.4x10^{6}$	$4.0x10^{4}$	25	$2.4x10^{5}$	22	$4.0x10^{4}$	25	$8.1x10^{5}$	25
	2	$1.7x10^{6}$	$1.8x10^{6}$	$2.4x10^{5}$	25	$5.6x10^{3}$	22	$2.5x10^{5}$	25	$1.2x10^{6}$	25
7	1	$2.8x10^{8}$	$1.8x10^{6}$	0.4	16	0.4	16	$7.7x10^{4}$	24	$1.7x10^{3}$	24
	2	$2.3x10^{6}$	$6.2x10^{9}$	0.5	16	0.5	16	7	24	$2.4x10^{4}$	24
8	1	$1.7x10^{7}$	$2.1x10^{7}$	0.7	30	40	30	0.7	30	40	30
	2*	$1.4x10^{7}$	----	<2	36	<2	36	<2	39	3.4	39
9	1	$3.6x10^{6}$	$1.2x10^{7}$	<0.4	30	$1.2x10^{2}$	30	$1.3x10^{2}$	37	$4.0x10^{2}$	37
	2a	$7.2x10^{6}$	$1.1x10^{7}$	<0.4	30	0.5	30	$8.3x10^{2}$	37	$4.4x10^{2}$	37
	2b	$7.2x10^{6}$	$1.8x10^{6}$	<0.5	37	8	37	0.5	37	8	37
	3*	$3.8x10^{6}$	$8.8x10^{6}$	<2	40	$<1.6x10^{2}$	40	<2	40	$<1.6x10^{2}$	40
10	1	$5.8x10^{7}$	$5.8x10^{7}$	**	**	**	**	$3.9x10^{5}$	22	$6.4x10^{3}$	22
	2	$9.4x10^{7}$	$9.4x10^{7}$	**	**	**	**	$1.4x10^{5}$	22	$1.4x10^{5}$	22
	3	$3.3x10^{8}$	$3.3x10^{8}$	**	**	**	**	$7.9x10^{5}$	22	$7.4x10^{5}$	22
11	1	$6.3x10^{7}$	----	$9.5x10^{6}$	20	$4.7x10^{5}$	20	$9.5x10^{6}$	20	$4.7x10^{6}$	20

* The numbers presented here are the average values for the various windrows which were tested using the same initial conditions (see Table 8).

** No intermediate data.

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TABLE 13. SUMMARY OF SALMONELLAE DATA FOR PHASE II WINDROW CYCLES

Run #	Windrow #	Initial Salmonellae Concentration MPN/g		Lowest Salmonellae Concentration MPN/g				Final Salmonellae Concentration MPN/g			
		Interior	Exterior	Interior	Day	Exterior	Day	Interior	Day	Exterior	Day
6	1	$5.3x10^{4}$	$1.2x10^{5}$	8.1	25	85	22	8.1	25	$4.1x10^{2}$	25
	2	$2.9x10^{3}$	$3.2x10^{3}$	< 18	22	$2.7x10^{2}$	22	$1.4x10^{3}$	25	$4.8x10^{2}$	25
7	1	$1.5x10^{5}$	$1.6x10^{3}$	0.2	19	0.2	19	$4.3x10^{5}$	24	$1.7x10^{3}$	24
	2	$9.3x10^{4}$	$1.3x10^{5}$	0.2	19	0.2	19	93	24	$7.4x10^{3}$	24
8	1	$6.1x10^{4}$	$1.9x10^{4}$	<2	30	<2	30	<2	30	<2	30
	2*	$1.4x10^{4}$	----	<7	36	<20	36	--	--	--	--
9	1	$1.2x10^{4}$	$7.5x10^{3}$	<0.2	30	<0.5	30	2	37	3	37
	2a	$3.3x10^{3}$	$5.3x10^{4}$	< 2	37	18	37	<2	37	18	37
	2b	$1.8x10^{5}$	----	<0.2	37	<0.2	37	<0.2	37	<0.2	37
	3*	$8.3x10^{3}$	$1.2x10^{4}$	7.5	26	$1.6x10^{3}$	26	--		--	
10	1	$5.8x10^{4}$	$5.8x10^{4}$	**	**	**	**	$7.4x10^{1}$	22	$1.8x10^{2}$	22
	2	$2.7x10^{5}$	$2.7x10^{5}$	**	**	**	**	$7.0x10^{3}$	22	$3.6x10^{3}$	22
	3	$1.2x10^{6}$	$1.2x10^{6}$	**	**	**	**	$7.3x10^{2}$	22	$2.4x10^{3}$	22
11	1	$5.8x10^{3}$	----	2.4	20	0.2	20	2.4	20	0.2	20

* The numbers presented here are the average values for the various windrows which were tested using the same initial conditions (see Table 8).

** No intermediate data.

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TABLE 14. SUMMARY OF VIABLE *ASCARIS* SP. OVA DATA FOR PHASE II WINDROW CYCLES

Run #	Windrow #	Initial Viable Ascaris Ova ova/g		Lowest Viable Ascaris Ova ova/g				Final Viable Ascaris Ova ova/g			
		Interior	Exterior	Interior	Day	Exterior	Day	Interior	Day	Exterior	Day
6	1	29	35	2	22	6	22	9	25	10	25
	2	24	40	6	11	3	11	12	25	7	25
7	1	<2	11	<1	24	1	24	< 1	24	1	24
	2	6	2	<1	21	<1	21	1	24	1	24
8	1	11	10	0.5	32	4	25	0.5	32	--	
	2*	22**		<0.7	51	<0.6	51	<0.7	51	<0.6	51
9	1	6.5	11	<0.8	23	0.8	37	1.9	37	0.8	37
	2a	9.6	14	<0.8	23	<1.1	23	<1.1	37	1.1	37
	2b	--	4.4	2.3	37	<0.6	37	2.3	37	<0.6	37
	3*	3.4	4.1	<2.2	18	<1.5	11	--		--	

* The numbers presented here are the average values for the various windrows which were tested using the same initial conditions (see Table 8).

** Composite of Interior and Exterior samples.

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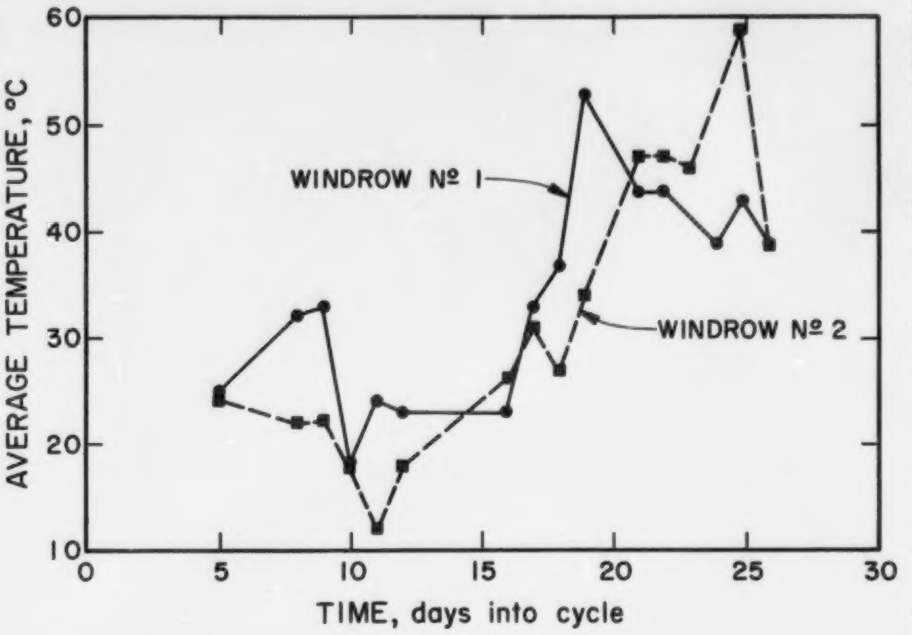

Figure 4. Average internal temperatures versus time for the windrows of Run 6.

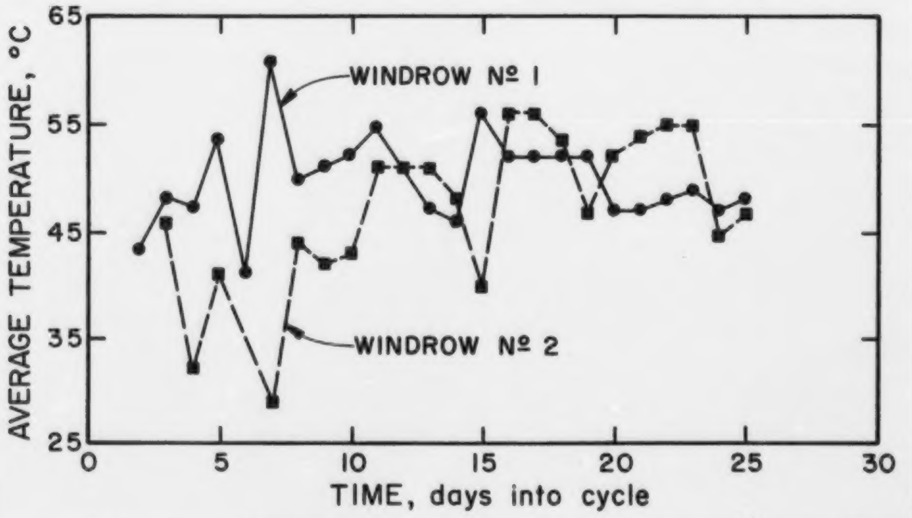

Figure 5. Average internal temperatures versus time for the windrows of Run 7.

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were achieved (Figure 5). The clumping phenomenon was again evident in Run 7. Consistent with the good temperature elevations of 55 to 60°C (131 to 140°F), bacteria and parasite inactivation was almost complete by day 19, despite the clumping of the compost. At this point in the compost cycle, 5.8 cm (2.3 in) of rain fell during days 19, 20, and 21 which caused a drop in windrow temperature, an increase in moisture content and ultimately a significant amount of bacterial regrowth. Total and fecal coliform levels increased to 10^6 and 10^4 MPN/g, respectively, by the end of the compost cycle. *Salmonella* sp. levels likewise were measured as high as 10^5 MPN/g. Levels of *Ascaris* sp. were not affected by rainfall, since these parasites cannot grow or complete their life cycle within a windrow.

In Run 8, an attempt was made to determine the cause of the clumping phenomenon. As mentioned earlier, it was theorized that clumping within the windrows was either due to the mixing of very dry and very wet components and/or polymer addition in the basket centrifuge station. Run 8 began with a total of four windrows. Windrow 1 was a control windrow, as in previous runs, and the remaining three windrows were made up of 100% dewatered cake (2:1 ratio of basket to scroll centrifuge). The three 100% cake rows were turned individually until day 24 of the cycle at which time they were combined into one row referred to as Windrow 2. Data prior to day 24 of the cycle for the three 100% cake windrows were averaged to give a single value.

Visual observations were made throughout the course of run 8 and no significant improvements in the clumping phenomenon were noted for the three windrows made with 100% cake. Both Windrows 1 and 2 exhibited the same characteristics as those of previous runs. Therefore, the theory of mixing wet and dry (centrifuge cake and dry compost) as a cause for clumping was discarded. Judging from the data, Run 8 exhibited signs of excellent composting. Total and volatile solids levels for Windrow 1 were identical to those of Runs 6 and 7, but unlike the previous runs, excellent bacterial and parasite inactivation occurred. The same holds true for Windrow 2 even though this windrow was started without any bulking agent. Both windrows experienced a temperature lag of 10 to 12 days (Figure 6).

Though average temperatures in excess of 60°C (140°F) were not recorded in Windrow 1, final levels of coliforms, salmonellae and *Ascaris* sp. ova were very low. On only 8 days was the average temperature in excess of 50°C (122°F), which first occurred on day 14 of the cycle. It is interesting to note here, that a uniform temperature elevation coupled with a consecutive 5 day period (day 22 to day 26) when average temperatures exceeded 50°C (122°F) was as effective for inactivating coliforms, *Salmonella* sp. and *Ascaris* sp. as was the more rapid elevation and higher temperatures reached in the previous cycle (before rains).

Run 9 was performed in an effort to determine what ratio of recycled compost would give the best overall result. A total of six windrows were constructed as follows:

Windrow 1 - one windrow made up of 0.84 m^3 of finished compost per metric ton of cake (1 yd^3/short ton).

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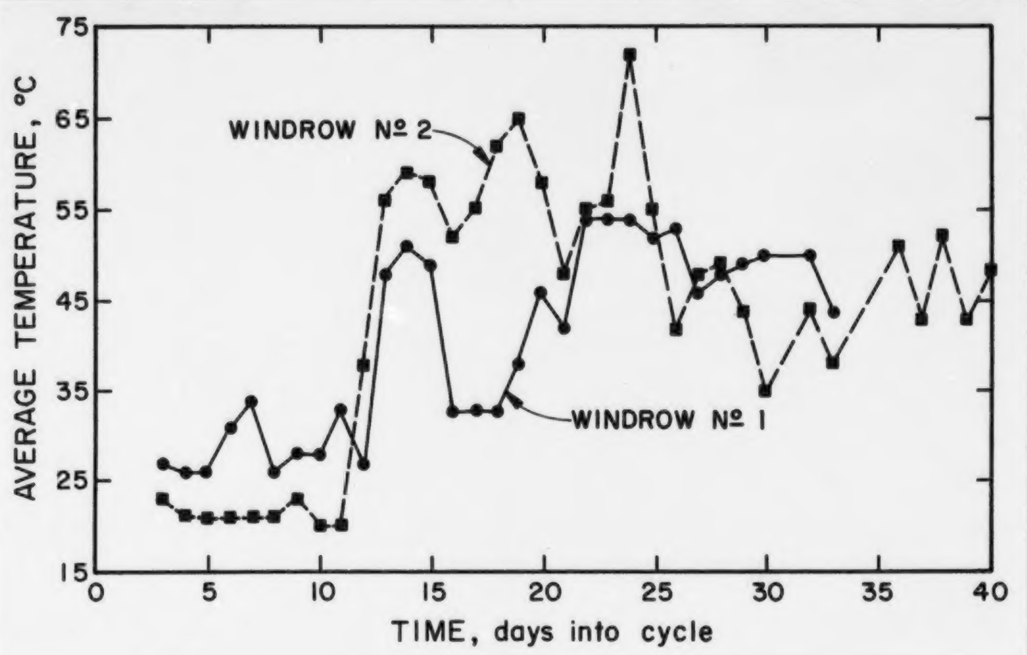

Figure 6. Average internal temperatures versus time for the windrows of Run 8

Windrow 2 - two windrows made up of 0.42 m^3 of finished compost per metric ton of cake (0.5 yd^3/short ton).

Windrow 3 - three windrows made up of 100% sludge cake and almost identical in composition to the sludge cake in Run 8 (2.1:1 of basket cake to scroll centrifuge cake).

Heavy rains totaling 5 cm (2 in.) on the second, third, and fourth day of the compost cycle caused the three 100% cake windrows to flow together and they had to be replaced on August 22, 1977. Note that only the 100% cake windrows were re-started, while the remaining three windrows were allowed to continue their cycle. Temperature lags of 12 and 20 days were experienced by Windrows 2 and 3, respectively. Windrow 1 was least affected by the rain since it was the driest at the start of the run. Good temperature elevations were achieved by all of the windrows as evidenced in Table 10 and Figure 7. The majority of the average temperatures ranged between 50° and 60°C (122 and 140°F) for the last two-thirds of the cycle for Windrows 1 and 2, and for the last third of the cycle for Windrow 3. Despite these excellent temperature elevations, the microbiological results were disappointing. Good pathogen inactivations were observed near the end of the cycle (days 30 to 35), however, the final samples taken indicated that a significant amount of regrowth had occurred (similar to Run 7).

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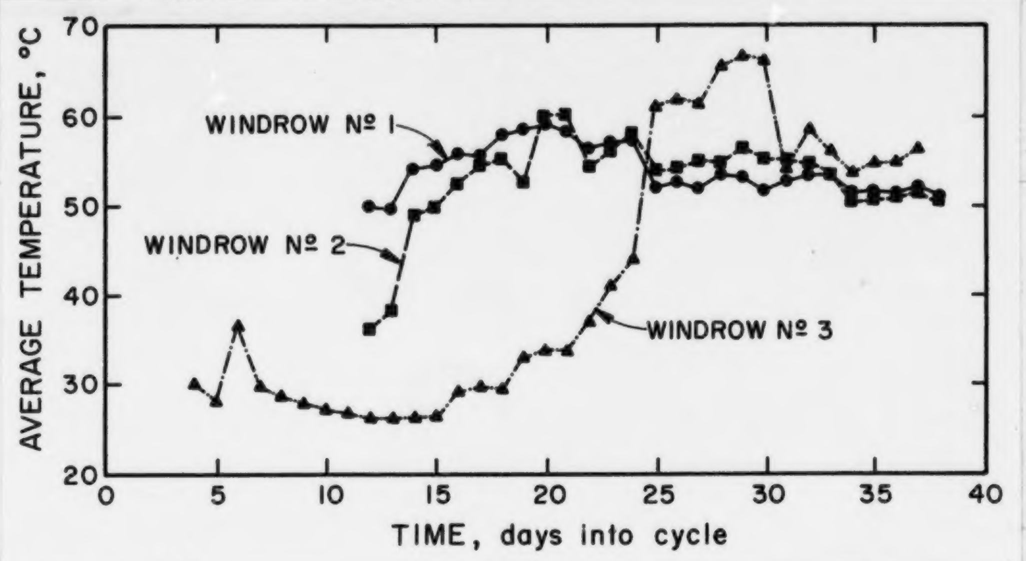

Figure 7. Average internal temperatures versus time for the windrows of Run 9

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The drying times for the windrows were the same (time to reach 60% TS) only because Windrows 1 and 2 received 5 cm (2 in.) of rain at the beginning of their cycles. Surprisingly, the time to reach 60% TS for the 100% cake windrow was only 28 days and was probably due to warm weather conditions during the run. Maximum ambient temperatures were typically 25 to 30°C (80 to 90°F) during most of the compost cycle, thus increasing significantly the rate of drying as compared to the previous runs. Typical drying times for conventional windrows with 0.84 m^3 of finished compost per metric ton of cake (1 yd^3/short ton) during the summer months are approximately 3 weeks.

During Run 9, eleven grain size analyses were performed to shed light on the clumping phenomenon. It was believed that the large clumps were not composting properly since the innermost portions of the clumps were black (possibly anaerobic). It was anticipated that the grain size analyses would show that the larger particles (clumps) would be considerably higher in volatile solids than the finer ones. Material was taken from windrows during the last week of the compost cycle, and was separated into six size ranges. Total and volatile solids analyses were performed for all particle size range groups to determine which of these groups had experienced the greatest amount of composting (volatile solids degradation). The results of the analyses indicated that between 40 and 50% of the material had particle sizes which were greater than 6.4 mm (0.3 in) and that between 20 and 25% of the material had particle sizes greater than 12.7 mm (0.5 in). Despite the wide variation in particle sizes, total and volatile solids analyses indicated very little change from one size to another. The larger particles, therefore, had experienced relatively the same amount of

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composting as the finer particles. It became evident that the clumping phenomenon was not the sole cause of poor bacterial and pathogen inactivation.

The inability of the composter to break up the clumps and to provide a uniformly porous windrow was evident in all the runs. The addition of the finer solids from the basket centrifuges, the introduction of polymer and the composter's inability to break up the large clumps may all have contributed to the clumping phenomenon.

Runs 10 and 11 were different from the previous runs in that several windrows were constructed with an alternate bulking agent in addition to recycled finished compost. In Run 10, Windrow 1 consisted of 0.84 m^3 of finished compost per metric ton of cake (1 yd^3/short ton). Windrow 2 was a mixture of 0.77 m^3 (1 yd^3) of finished compost, 0.77m^3 (1 yd^3) of rice hulls and 0.91 metric ton (1 short ton) of sludge cake. Windrow 3 was the same as Windrow 2 except wood shavings were used instead of rice hulls as the alternate bulking agent. For comparison, a separate windrow (Run 11) was tested one month later with a mixture of 0.77 m^3 (1 yd^3) of finished compost, 0.77 m^3 (1 yd^3) of tree trimmings and 0.91 metric ton (1 short ton) of sludge cake.

From Table 9 it is evident that windrows containing alternate bulking agents were considerably higher in both total and volatile solids levels than the control windrow. Volatile solids concentrations were 76% and 99% respectively for rice hulls and wood shavings. As shown in Figure 8, Run 10 windrows experienced rapid temperature elevations, with Windrow 2 experiencing the highest temperature and Windrow 1 the lowest. Windrow 1 temperature elevation was not as high as the windrows constructed with the alternative bulking agents, thus indicating that the increase in volatile solids due to the addition of these bulking agents resulted in increased windrow temperatures. Maximum average temperatures for Windrow 1 were between 50 and 55°C (122 and 131°F), while for Windrows 2 and 3 they were between 55 and 60°C (131 and 140°F). The windrow laid with tree trimmings (Run 11), experienced a temperature lag and lower overall temperatures when compared to the other three windrows. This lag was probably due to the problems encountered while mixing the materials, resulting in a mixture that was not of uniform blend.

Most of the shredded tree trimmings consisted of shredded leaves, twigs, bark, and a considerable amount of large pieces (sections of branches). These materials were up to 0.3 m (1 ft) long and 2 to 5 cm (1 to 2 in) in diameter. Unlike the procedure for mixing cake and finished compost, mixing this windrow was accomplished by putting equal volumes of cake, compost and tree trimmings on the ground and then mixing with a front end loader. This mixture was then placed into a conveyor bottom trailer, but experienced great difficulty in unloading the material to form a windrow. Once mixed and constructed into a windrow, the composter also experienced difficulty in getting through and processing the row. This machine eventually broke down, and as a result, the windrow was not turned properly for the first week of the cycle. The tree trimmings were

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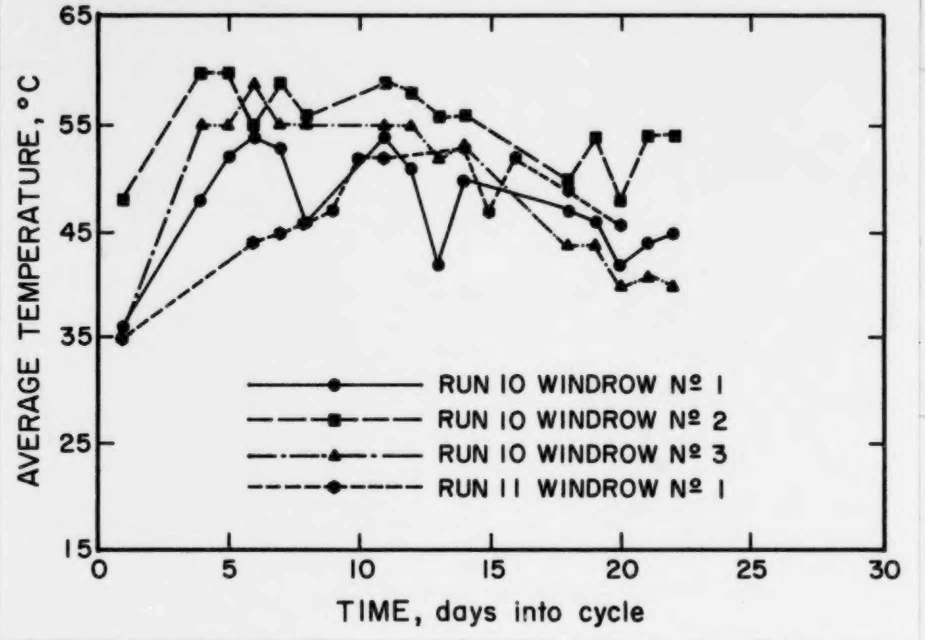

Figure 8. Average internal temperatures versus time for the windrows of Runs 10 and 11

acquired from a local city, and were judged unsuitable for use as a bulking agent in the condition which they were received.

Run 10 windrows were turned once per day during their cycles. Bacterial data (Tables 11, 12, and 13) indicate poor inactivation of coliforms in Runs 10 and 11. Total coliform data indicate that a fair degree of inactivation had occurred by day 11 for Run 10, but by the end of the cycle, coliform levels had increased to very high levels (10^5 to 10^6 MPN/g). No intermediate data were collected for fecal coliforms and salmonellae, and therefore, it is impossible to determine whether or not some inactivation with subsequent regrowth took place for these organisms. Run 11 showed very little, if any, inactivation of total coliforms, fecal coliforms and salmonellae. Parasite samples were not analyzed for either Run 10 or 11.

An unsuccessful attempt was made to build a windrow that would not be turned mechanically, but rather would utilize a forced aeration system in order to supply the compost material with oxygen. A windrow with slightly larger dimensions than normal was placed on an air system which consisted of two 10 cm (4 in) diameter air lines spaced 90 cm (3 ft) apart, and

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connected at the ends to form a closed loop 12 m (40 ft) long. Air was drawn through the lines using a 0.25 kw (0.5 hp) blower at a rate of approximately 50 l/sec (100 cfm). While the windrow was being placed onto the air lines, it rained 0.5 cm (0.2 in). This caused the sludge to become wetter and more difficult to pile. The final dimensions of the windrow were 1.2 m (4 ft) high, 3.8 m (12.5 ft) wide, and 15 m (50 ft) long. In the first 13 days of operation it rained a total of 10.5 cm (4.1 in), and the entire compost field was rendered inoperable. The air system filled with water as early as day 5. The flow rate through the pile decreased from 60 l/sec (130 cfm) to 40 l/sec (80 cfm) while the pressure drop through the pile increased from a negligible amount to 13 cm H_2O (5 in). Temperatures never exceeded 45°C (113°F) for the entire run (19 days), and though no final bacterial samples were collected due to poor performance, it is highly probable that little inactivation occurred within the windrow. The rains which caused this run to fail continued, and the compost field was unusable during the entire winter of 1978. By March 1978, the basket and scroll centrifuge stations were converted to parallel operation and, therefore, no other experiments were conducted using combined cake from the series operation.

During Runs 9 and 10, windrows were routinely monitored for odor emissions throughout their compost cycles. The results of the odor sampling are plotted in Figure 9. It is evident that the majority of the odor is emitted during the first week of a compost cycle. Very high dilution ratios of 400 were observed during the first few days. After the first week of the windrow compost cycle, odor dilution ratios within the samples decreased significantly and leveled off at 10 to 20. Acceptability of odor levels are a function of local conditions; for this site, however, the latter odor levels are considered acceptably low under most weather conditions.

Summary

The addition of basket centrifuge cake had a detrimental effect on the windrow composting operation at the JWPCP. The method of building windrows did not insure a uniform mixture of wet cake and finished compost at the start of the compost cycles and yielded a windrow which varied noticeably in moisture content and was uneven in height. As a result, all of the material did not experience the same degree of composting since internal temperatures varied widely throughout the windrow.

Adequate bacterial and pathogen inactivation was achieved when composting the two-stage cake, but not in a consistent manner. When the basket centrifuges became operational, average temperatures within the windrow dropped and bacterial inactivations were not as rapid during the first 10 days of composting as had been experienced in the past. Final total coliform counts averaged 10 to 100 times the number achieved with scroll centrifuge cake alone. Salmonella sp. counts were also consistently higher. The decreased maximum temperatures may have been the result of the increased ratio of finished compost to dewatered cake, as necessitated by the wetness of the basket cake, and of the poorer mixing characteristics of the two stage cake.

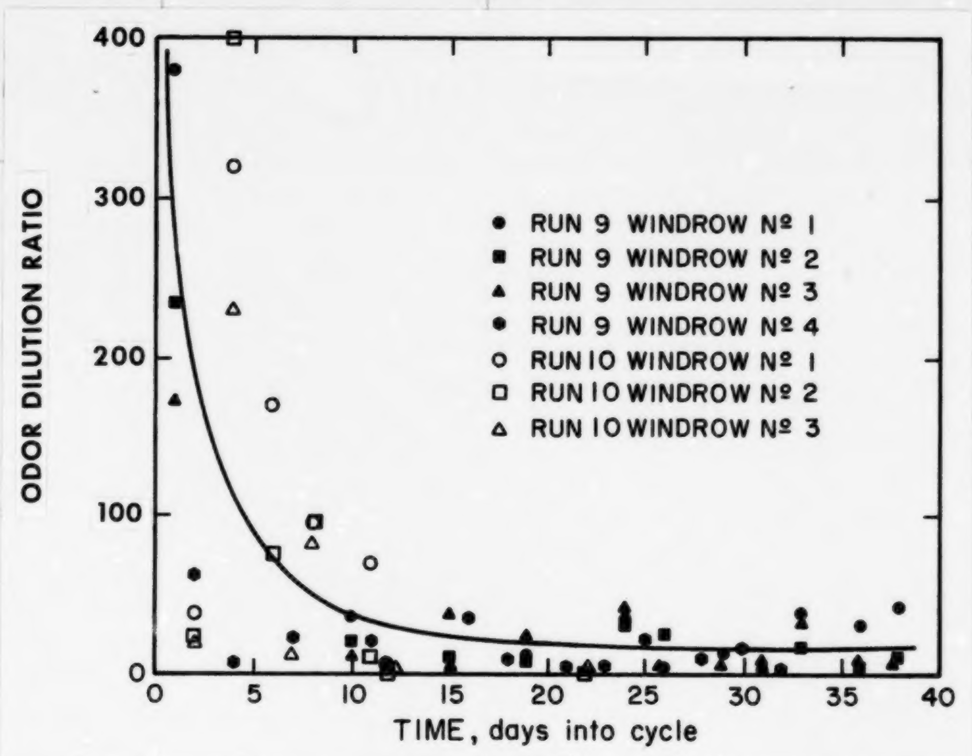

Figure 9. Daily odor levels versus time
for the windrows of Runs 9 and 10.

Internal temperatures proved to be a valuable indication of microorganism destruction and the general degree of composting. Seasonal variations directly affect the compost process since the operation is not covered or enclosed.

A clumping phenomenon was evident in the compost material as a direct result of the addition of the basket cake. These clumps pose a problem from a product acceptance point of view. The mechanical composter was not able to break up the clumps.

PHASE III RESULTS

Phase III studies began in June 1978 with the observation that deeper windrows increased the productivity of the site and improved composting performance (more consistent temperature elevations and microoganism inactivations) of the sludge cake from the two-stage centrifugation system. Using deeper windrows was made possible by the availability of a turning machine (SCARAB composter) to adequately process the deeper windrows.

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Operational Factors Influencing Composting Performance

Windrow Size --

Monitoring of windrow performance of the full-scale plant operation began in June 1978. The windrows were routinely monitored for microorganism levels at the completion of the compost cycle. Samples were collected and analyzed on a weekly basis. The data, with few exceptions, indicated levels of total and fecal coliform well in excess of the limit of 10 MPN/g which had been proposed by the LACSD microbiological section. About 50% of the samples contained *Salmonella* sp. in excess of the suggested limit of 1 MPN/g. *Ascaris* ova concentrations appeared to be near the detection limit of 0.5 viable ova/g. Routine monitoring, therefore, indicated that the full size plant operation with smaller windrows had not produced optimum inactivation of microorganisms. However, it was observed in the research studies that some larger windrows, 1.2 to 1.5 m (4 to 5 ft) high, performed better compared to the smaller typical 0.7 to 1.1 m (2.5 to 3.5 ft) high windrows. It was decided that further research should be conducted on the construction, operation, and performance of 'deep' windrows.

Utilizing deeper windrows was made possible by a new type of turning device. The new machine (a Scarab composter) has the capability to turn a deeper windrow than did the type previously used. The windrows were also more uniform in height, and the compost material appeared finer in texture. The deep windrows were constructed with a maximum 4.3 m (14 ft) base and 1.2 to 1.5 m (4 to 5 ft) high. The deep windrows appeared to give excellent temperature elevation and pathogen destruction. Several factors that could affect deep windrow performance were investigated. These factors include drying rate, odor and dust emissions, methods for building and turning large windrows, and performance during less than optimum weather conditions.

Initial research studies used smaller windrows to compost sludge cake produced from series operation of the scroll and basket centrifuges. In early 1978, parallel operation of the scroll and basket centrifuges began, changing the dewatered sludge quality. Therefore, it is difficult to make comparisons between earlier, small windrow runs and later runs with deep windrows. However, some comparisons can be made between the research windrows studied since June 1978 and the smaller windrows from full-scale JWPCP operation which were routinely monitored during the same period.

As noted earlier, the small windrows used for full-scale composting at the JWPCP produced inconsistent inactivation of microorganisms. By comparison, data from the experimental deep windrows indicated excellent temperature elevations, virtually no pathogenic organisms, and only trace coliform organisms in the final compost product. (Data are presented and discussed in detail in a later section.) Additionally, deep windrows require a smaller land area for a given amount of sludge to be composted; e.g., about 10% more sludge can be composted using deep windrows than small windrows on the same amount of land surface. These advantages combined with the success of the experimental deep windrows led to the present full-scale deep windrow composting at the JWPCP which began in January 1980.

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Windrow Turning Frequency --

Turning of the windrow is important for three reasons: 1) It results in a well mixed, homogeneous windrow assuring that all of the compost material is exposed to the high internal temperatures; 2) it aerates the compost material and maintains porosity; and 3) it assists in the drying process. During typical full-scale plant operation, windrows are now turned 3 times per week, while past practice was to turn the windrows 5 times per week.

Windrow Runs 6, 17, and 18 were conducted specifically to evaluate the effects of turning frequency on composting performance. A summary of the results for these three runs is presented in Table 15. The results for Run 6 indicated no benefit in turning Windrow 2 twice per day versus once per day for Windrow 1. The drying rate was not increased, nor were the microorganism kills significantly different.

During Run 17, turning frequencies ranging from 1.6 to 2.9 times per week were evaluated. Again, drying times were not significantly affected by turning frequency. All of the windrows reached a value of 60% TS in 24 to 28 days. Although there was some effect on the rate at which elevated temperatures were achieved by varying the turning frequency of the windrows, all windrows experienced high internal temperatures. Average internal temperatures first reached 55°C (130°F) between days 20 and 25 for the majority of the windrows. These temperatures were maintained for approximately 10 days, and began to decrease after day 35 of the cycle. The fact that internal temperatures could be maintained adequately by using a turning frequency of less than once per day was an important finding, since it was mentioned earlier that the drying rate was also not significantly affected by varying the turning frequency.

The most complete study of the effects of windrow turning frequency was conducted during Run 18. Windrows 1 through 3 were constructed with a mixture of 1.6 m^3 of finished compost per metric ton of sludge cake (1.9 yd^3/short ton) and Windrows 4 through 6, with 2.5 m^3/metric ton (3.0 yd^3/short ton). Turning frequencies were 5/week, 3/week and 2/week for Windrows 1 and 4, 2 and 5, and 3 and 6, respectively. The time needed to reach 60% total solids for Run 18 was affected by the turning frequency (Figures 10 and 11). The cycle times needed to reach 60% TS for Windrows 1, 2, and 3 were 26 days, 33 days, and 39 days, respectively. For Windrows 4, 5, and 6 they were 31 days, 33 days, and 37 days, respectively. Thus, though turning does seem to have some effect on drying rates, the benefits obtained by daily (5/week) turning do not seem to be consistent, especially when comparing the results of Windrows 4 and 5 (Figure 11). Here the difference in the drying time to reach 60% TS was only 2 days when turning was on a M-W-F schedule instead of M-T-W-Th-F.

Turning the deep windrows five times per week did not achieve temperature elevations any different than those turned three times per week. In fact, temperatures for windrows turned less often were consistently higher, especially during the latter part of the compost cycle (Figures 12 and 13). At the end of the compost cycle, temperature levels within the windrows which were turned five times per week (Windrow 1 and Window 4)

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TABLE 15

EFFECTS OF TURNING FREQUENCY ON WINDROW PERFORMANCE FOR RUNS 6, 17, and 18

RUN NUMBER	WINDROW NUMBER	AVERAGE TURNING FREQUENCY PER WEEK	TIME (days)							FINAL MICRO DATA		
			To Reach 60%TS[a]	To Reach Average Temp °C			Average Temp Exceeded °C			Total Coliform MPN/g	*Salmonella* sp. MPN/g	Viable *Ascaris* sp. ova/g
				50 (122°F)	55 (131°F)	60 (140°F)	50 (122°F)	55 (131°F)	60 (140°F)			
6	1	7	21	19	-	-	1	0	0	8.1×10^5	410	9
	2	14	24	24	-	-	1	0	0	2.5×10^5	480	12
17	1	2.9	25	22	29	-	12	5	-	0.5	<0.2	1.5[b]
	2	1.9	28	16	27	-	13	5	-	0.5	<0.2	1.5
	3	1.6	26	16	22	-	14	6	-	1.4	<0.2	1.5
	4	2.7	24	22	23	-	11	6	-	0.6	<0.2	1.5
	5	2.9	28	19	23	-	10	5	-	2.8	<0.2	-
	6	1.9	28	19	25	30	12	6	1	1.3	<0.2	-
	7	1.6	-	16	25	-	15	3	-	0.6	<0.2	-
	8	2.7	31	20	29	30	14	6	2	0.6	<0.2	-
18	1	5	26	15	24	-	22	2	-	21	<0.2	-
	2	3	33	17	24	-	19	10	-	11	<0.4	-
	3	2	39	17	22	35	25	18	5	2	<0.2	-
	4	5	31	14	20	-	25	10	-	21	<0.2	-
	5	3	33	14	19	-	25	14	-	13	<0.2	-
	6	2	37	14	14	22	25	22	-	4	<0.2	-

[a] For Run 17, time to reach 55% TS is given (60% TS never achieved).
[b] Result from a composite sample of windrows 1 to 4.

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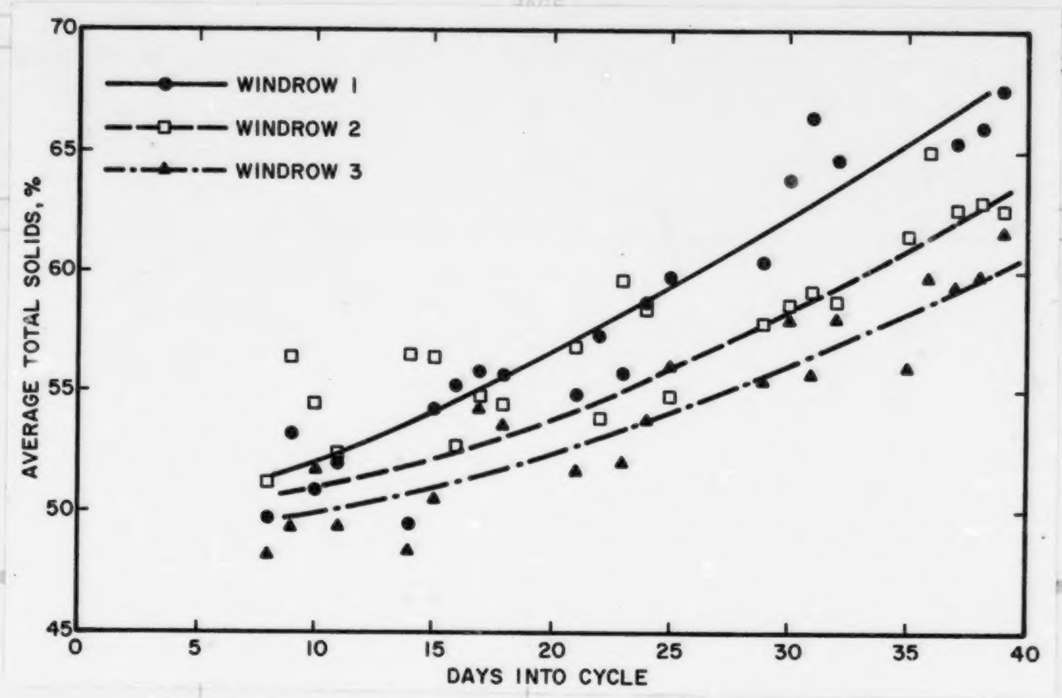

Figure 10. Total solids versus days into cycle for Windrows 1, 2 and 3 of Run 18.

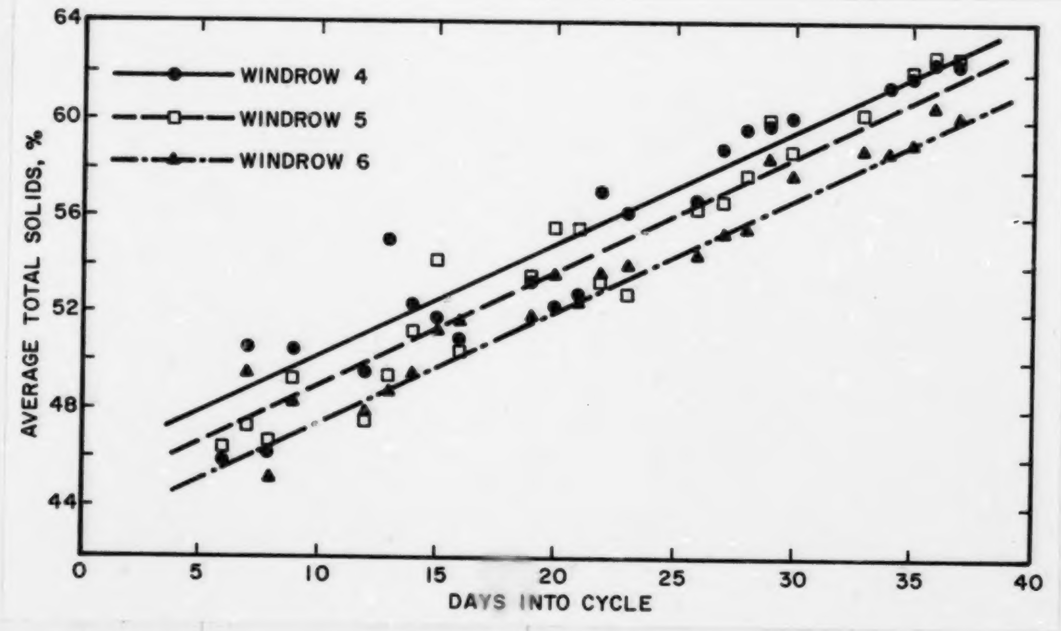

Figure 11. Total solids versus days into cycle for Windrows 4, 5 and 6 of Run 18.

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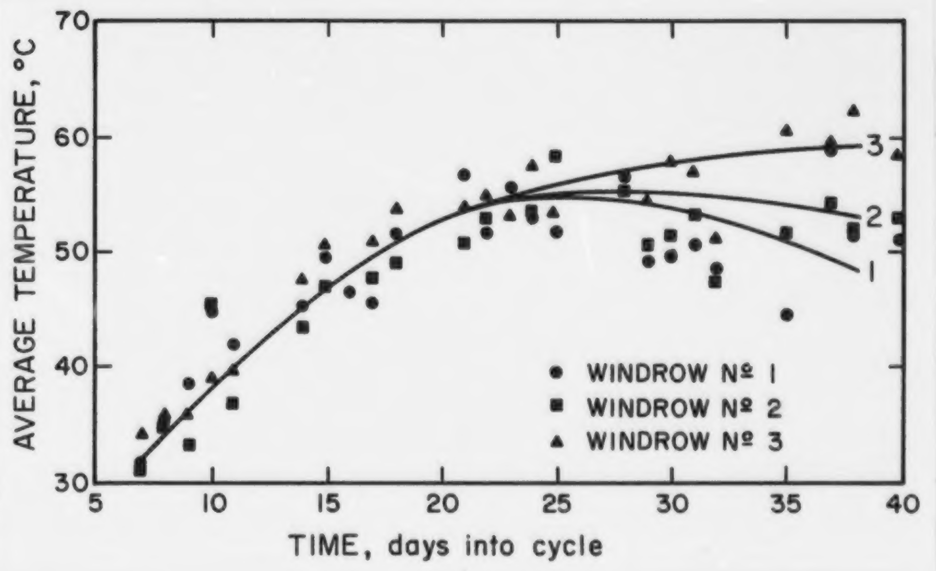

Figure 12. Average internal temperatures versus time for Windrows 1 through 3 of Run 18.

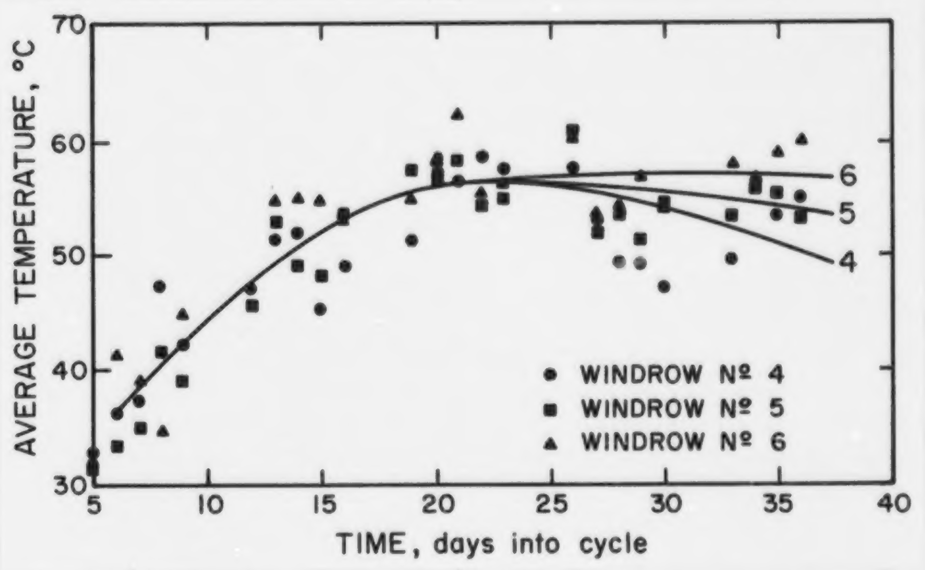

Figure 13. Average internal temperatures versus time for Windrows 4 through 6 of Run 18.

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decreased, apparently as a result of excessive moisture loss. Windrows 3 and 6 were able to maintain elevated temperatures for longer periods than the other windrows. Thus, frequent turning may not be desirable if maintaining high temperatures is of concern.

Temperature profiles were obtained for each windrow to further assess the effect of turning. Monitoring was conducted late in the compost cycle during periods of elevated temperatures. A total of 42 measurements were made for each windrow at various locations within the cross-section. Using these values, the contours which appear in Figures 14 and 15 were drawn. Note that Windrows 1 and 4, which were turned five times per week, did not achieve the same temperature elevation within their cross-sections as the other windrows. Though temperatures in excess of 60°C (140°F) were achieved in all cases, windrows which were turned less often contained larger areas of elevated temperatures.

It is also interesting to note the effect of sunlight on the internal temperatures of the windrows in Figures 14 and 15. In all cases, the side of the windrow which faced directly into the sunlight showed elevated temperatures within a few inches of the surface. The same was not true for the side which received indirect sunlight. Elevated internal temperatures were also skewed toward the side of the windrows facing directly into the sunlight. This sunlight effect could be of significance when considering outdoor versus enclosed composting operations.

Microbiological data presented in Table 15 indicates that final pathogen concentrations were not affected by varying the turning frequency. Essentially complete bacterial kills were detected as early as days 23 and 24 for some of the windrows in Run 17, but by day 31 all samples collected for Windrows 1 through 4 were either at or near the detection limit for the bacterial organisms. Windrows 5 through 8 reached this level by day 37, but it should be noted that sampling had not been conducted for two weeks prior to this, and that most likely, excellent kills occurred before day 37. In summary, excellent inactivation of bacteria occurred for all the windrows in Run 17.

Final microbiological data for the windrows of Run 18 also indicate that the varied turning frequencies had little effect on microorganism kills (Tables 15, 16 and 17). Organism levels steadily decreased in all windrows, and by day 35 the material had undergone virtually complete inactivation for the organisms tested. The final microbiological sample locations for Run 18 are shown in Figure 16.

Based on these research results, the present turning frequency for the full-scale operation is 3 times per week. It would be interesting at a later time to leave a windrow unturned and monitor the effects. Ideally, knowing the minimum number of turns required for acceptable pathogen inactivation and sludge drying rate is desirable, since this reduces operation and maintenance time and costs.

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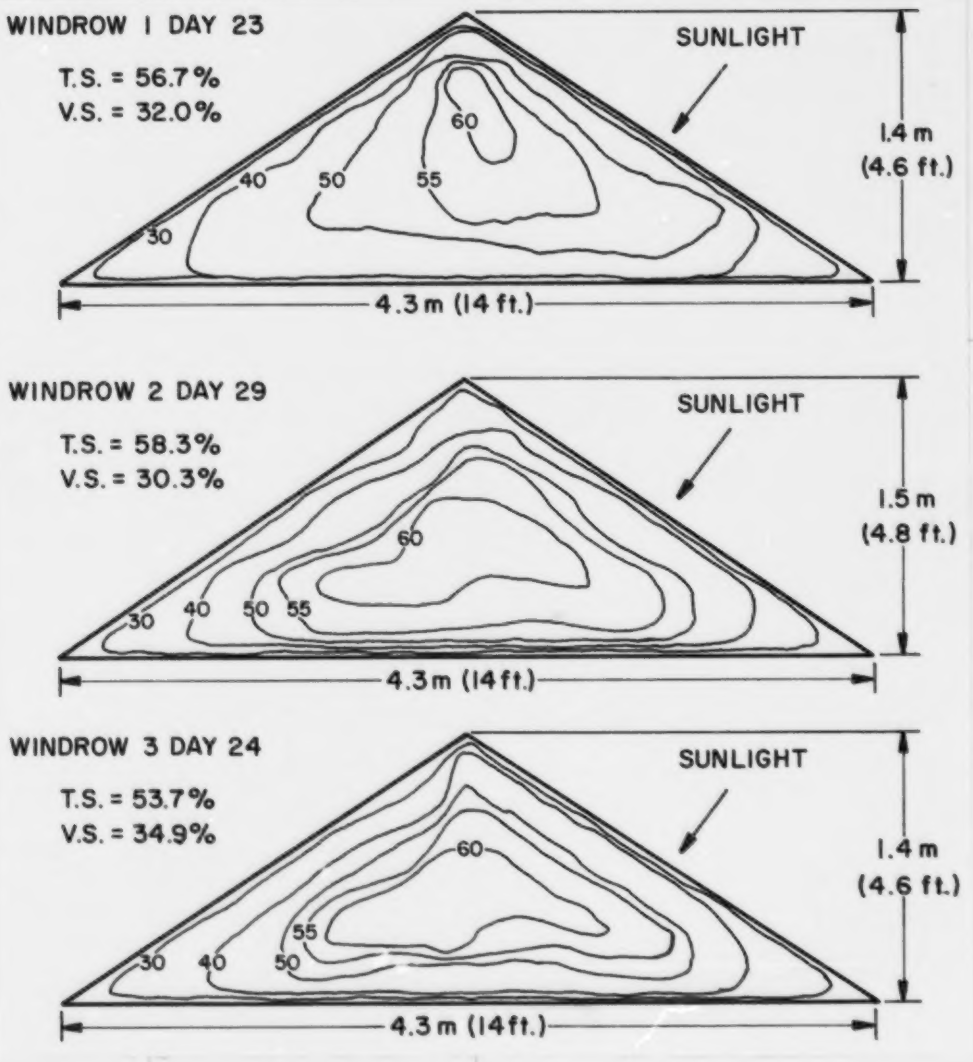

Figure 14. Temperature contour diagrams for Windrows 1 through 3 of Run 18.

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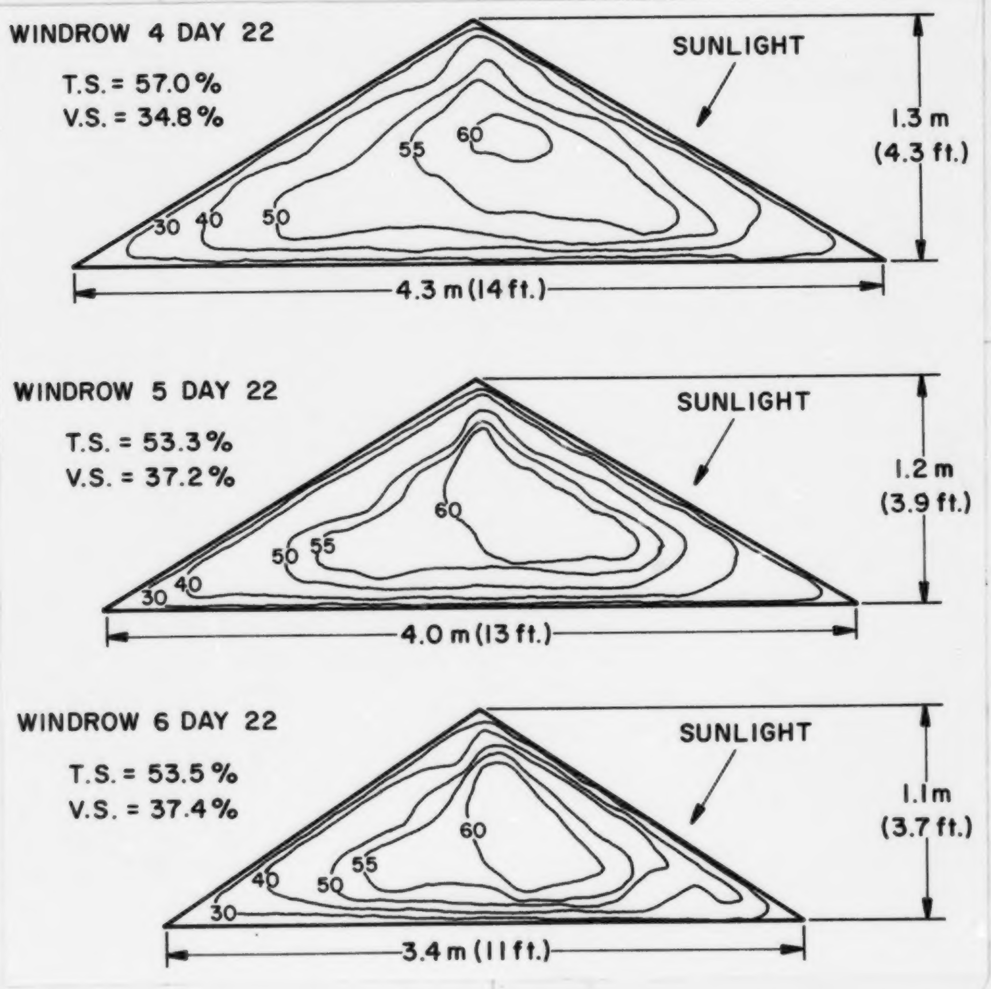

Figure 15. Temperature contour diagrams for Windrows 4 through 6 of Run 18.

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TABLE 16. SUMMARY OF MICROBIOLOGICAL DATA FOR WINDROWS 1, 2 AND 3 OF RUN 18*

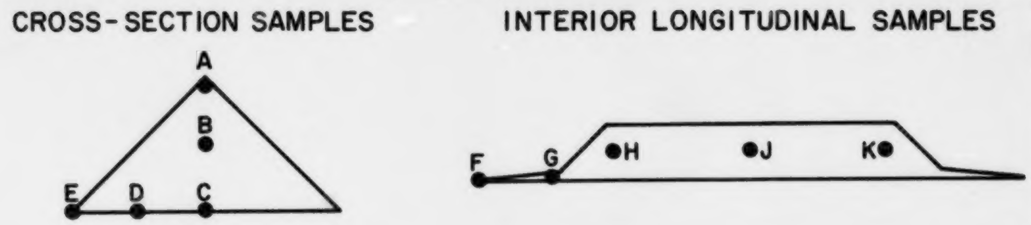
START UP FOR WINDROWS	DAY OF CYCLE	NUMBER OF SAMPLES	AVERAGE TOTAL COLIFORM (MPN/g)	AVERAGE FECAL COLIFORM (MPN/g)	AVERAGE SALMONELLAE (MPN/g)	AVERAGE ASPERGILLUS (cfu/g)
CAKE	0	3	4.0×10^7	4.6×10^6	2.7×10^3	<22
MIXTURE	0	6	4.7×10^6	1.3×10^6	1.9×10^2	<11
WINDROW #1	8	3	1.5×10^6	8.4×10^6	8.7×10^1	<9.4
	15	3	6.8×10^4	2.5×10^4	1.7×10^1	<9.3
	22	3	5.4×10^1	2.0×10^1	<0.5	<8.8
	29	3	3.5×10^2	7.0×10^1	<0.2	<7.8
	35	8	21	6	<0.2	<14
WINDROW #2	8	2	3.8×10^6	8.1×10^5	4.9×10^1	<9.4
	15	3	6.8×10^4	1.1×10^4	5.5	<9.3
	22	3	9.1×10^1	8.2×10^1	<0.5	<8.8
	29	3	1	1	<0.2	<8.5
	38	8	11	4	<0.4	<7.9
WINDROW #3	8	3	3.9×10^6	9.7×10^5	1.1×10^2	<9.4
	15	3	1.2×10^4	4.8×10^3	1.5	<9.3
	22	3	6.6×10^3	5.0×10^3	<0.8	<8.8
	29	3	5	3	<0.2	<8.6
	42	8	2	1	<0.2	<7.9

* All average values calculated using Geometric Means.

TABLE 17. SUMMARY OF MICROBIOLOGICAL DATA FOR WINDROWS 4, 5 AND 6 OF RUN 18*

START UP FOR WINDROWS	DAY OF CYCLE	NUMBER OF SAMPLES	AVERAGE TOTAL COLIFORM (MPN/g)	AVERAGE FECAL COLIFORM (MPN/g)	AVERAGE SALMONELLAE (MPN/g)	AVERAGE ASPERGILLUS (cfu/g)
CAKE	0	3	2.5×10^6	9.1×10^5	5.5×10^2	<22
MIXTURE	0	6	1.1×10^6	2.3×10^5	3.5×10^1	<10
WINDROW #4	8	3	8.5×10^5	3.1×10^5	8	<11
	15	3	2.2×10^5	1.2×10^5	2	<9.8
	22	3	1.3×10^2	5.0×10^1	<0.6	<9.3
	33	8	21	7	<0.2	86
WINDROW #5	8	3	8.5×10^4	3.7×10^4	1	<11
	15	3	8.5×10^4	1.8×10^4	<0.7	<9.8
	22	3	1.3×10^2	6.1×10^1	<0.6	<9.3
	36	8	13	3	<0.2	<8.1
WINDROW #6	8	3	1.4×10^5	1.2×10^5	1	<11
	15	3	3.4×10^2	1.9×10^2	<0.6	<9.8
	22	3	7	<0.6	<0.6	<9.3
	40	8	4	2	<0.2	31

* All average values calculated using Geometric Means.



A	TOP SURFACE SAMPLE	F	MATERIAL THROWN FROM WINDROW DURING TURNING
B	INTERIOR SAMPLE	G	MATERIAL AT TOE OF WINDROW
C,D,E	GROUND LEVEL SAMPLES	H,J,K	RANDOM INTERIOR SAMPLES

Figure 16. Final Microbiological sampling locations for Windrows 1 through 6 of Run 18.

Recycle of Finished Compost --

It is necessary to mix finished compost with dewatered sludge cake in order to provide each windrow with the proper starting total solids content. The amount of recycle is important since it can greatly affect cycle time, land requirements, material handling, and pathogen inactivation. A study of the effects of percent recycle on composting performance was made in Runs 12 and 16 (Tables 2 and 18). Both runs were made to determine what recycle ratio would give the best overall results. Results from the two runs are presented below and significant findings are summarized at the end of this section.

The six windrows of Run 12 were begun in June 1978. Windrows 1 to 6, respectively, consisted of various blends of finished compost and wet sludge cake, 2.5:1, 2.1:1, 1.7:1, 1.3:1, 0.8:1, and 0.4:1, in terms of m^3 of finished compost per metric ton of sludge cake (3:1, 2.5:1, 2:1, 1.5:1, 1:1, and 0.5:1 yd^3/short ton). Some significant results for these windrows are presented in Table 18.

Initial total solids contents of the windrows were 55% for Windrow 1, 55% for Windrow 2, 52% for Windrow 3, 50% for Windrow 4, 46% for Windrow 5, and 35% for Windrow 6. The times to reach 60% total solids were 7 days, 6 days, 10 days, 10 days, 13 days, and 17 days, respectively, for Windrows 1 through 6. The time required to reach 65% TS was consistent with this, and the values for Windrows 1 through 6, respectively, are 11 days, 11 days, 16 days, 14 days, 17 days, and 23 days.

The initial volatile solids content of each of the windrows varied since the ratio of finished compost and wet cake used was different. Volatile solids content is inversely proportional to the amount of finished compost added per ton of cake. Volatile solids for each windrow showed a slight decrease throughout the cycle. The total solids data indicate that the drying progressed satisfactorily for each windrow. Certain windrows exhibited poor temperature elevations during the cycle. Windrows 1 and 2 began to heat up almost immediately since they were the driest and

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TABLE 18. FINISHED COMPOST RECYCLE STUDY FOR RUNS 12 and 16

WINDROW NUMBER		MIXTURE m^3/metric ton of cake (yd^3/short ton of cake)	TOTAL SOLIDS			VOLATILE SOLIDS		TEMPERATURE °C (Days to Reach)				ODOR CONCENTRATION		TOTAL COLIFORM (MPN/g)	
			Initial %	Final[a] %	Time to 60% TS (days)	Initial %	Final[a] %	45 (113°F)	50 (122°F)	55 (131°F)	60 (140°F)	Max Value OU/SCM (OU/SCF)	Day	Initial	Final
1	RUN 12	2.5:1 (3:1)	55	69	7	35	34	-	2	4	6	710 (20)	7	$2x10^{6}$	500
2		2.1:1 (2.5:1)	55	67	6	36	35	-	1	3	7	1235 (35)	7	$4x10^{6}$	15
3		1.7:1 (2:1)	52	66	10	37	34	-	4	5	-	710 (20)	20	$1x10^{5}$	5
4		1.3:1 (1.5:1)	50	79	10	36	36	4	5	18	-	2,650 (75)	7	$8x10^{6}$	20
5		0.8:1 (1:1)	46	66	13	39	37	13	14	19	-	1,410 (40)	13	$8x10^{6}$	$5x10^{3}$
6		0.4:1 (0.5:1)	35	61	17	42	38	18	20	-	-	710 (20)	7	$5x10^{6}$	$4x10^{6}$
1	RUN 16	0.8:1 (1:1)	44[c]	62[b]	38	43	42[b]	14	28	28	30	7,060 (200)	14	$5.2x10^{7}$	9.1
2		1.3:1 (1.5:1)	44	64	34	43	41	8	16	26	-	9,890 (280)	6	$2.7x10^{7}$	$1.3x10^{2}$
3		1.7:1 (2.0:1)	50	63	28	43	41	6	7	12	16	4,240 (120)	6	$4.6x10^{7}$	0.6
4		2.1:1 (2.5:1)	54	65	16	43	41	2	5	7	8	2,470 (70)	6	$1.4x10^{7}$	6.1

[a] These final values are only through Day 21 of the compost cycle.

[b] These final values are through Day 32 of the cycle.

[c] After several days of turning.

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contained no excess moisture. Moisture is required for biological activity, but also can act as a heat sink inhibiting temperature rise. These windrows both experienced average temperatures in excess of 60°C (140°F) within the first week of composting, which is quite rapid in comparison with most previous experiences. It is interesting to note that within a week both total and fecal coliforms were almost completely inactivated, coinciding with the excellent temperature elevations. Around day 7 the temperatures began to drop and an increase in coliform content was observed (Figure 17). By the end of the compost cycle, the amounts of total and fecal coliforms had once again dropped, with final total coliform contents of 500 MPN/g and 11 MPN/g, respectively, for Windrows 1 and 2. Windrows 3 and 4, however, exhibited a much more uniform rate of coliform inactivation. By the end of the compost cycle both windrows were within the suggested limits (10 MPN/g) for total and fecal coliform in finished compost. Average temperatures for these two windrows did not rise as high as in Windrows 1 and 2, but were sufficiently high to achieve good coliform inactivation.

Windrows 5 and 6 performed the most poorly of all the windrows. Average internal temperatures did not exceed 45°C (113°F) until days 13 and 18 of the respective cycles, the lag being due to the excessive moisture content of these windrows. Microbial data indicate that both total and fecal coliform contents of the finished compost from these windrows were very high. *Salmonella* sp. were reduced below detection levels in all windrows except 5 and 6; final sample concentrations for Windrows 1 through 4 were <0.2 MPN/g. The average salmonellae content of Windrows 5 and 6 at the end of the compost cycle were 17 and 27 MPN/g, respectively.

It is desirable to minimize the amount of recycle used in order to decrease materials handling. Run 12 showed that high recycle ratios were not necessary to achieve good results, and that low recycle ratios would result in poor temperature elevation and pathogen inactivation. Run 16 was set up with a narrower range of recycle ratios.

Run 16 was begun in July 1979 and consisted of four windrows with mixture ratios as noted in Table 18. This study also differed in that deeper windrows were constructed. The dimensions of the windrows were 1.5 m (5 ft) high, 4.3 m (14 ft) wide at the base and 76 m (250 ft) long. A summary of pertinent results is presented in Table 18 for the four windrows tested. All four windrows were turned daily with the exception that during the period between days 14 and 25, the windrows could not be turned due to equipment failure. The windrows were constructed by laying two normal size windrows (as could be readily constructed with the trucks available) along side of each other. These were turned with the mechanical composter and then combined into one large windrow by use of a front-end loader.

Windrow 4 was the first to achieve the desired final total solids content of 60% (day 16 of the compost cycle), since it contained the largest amount of finished recycled compost. The other windrows experienced a steady increase in TS, but the time to reach 60% TS was considerably longer due to their high initial moisture contents.

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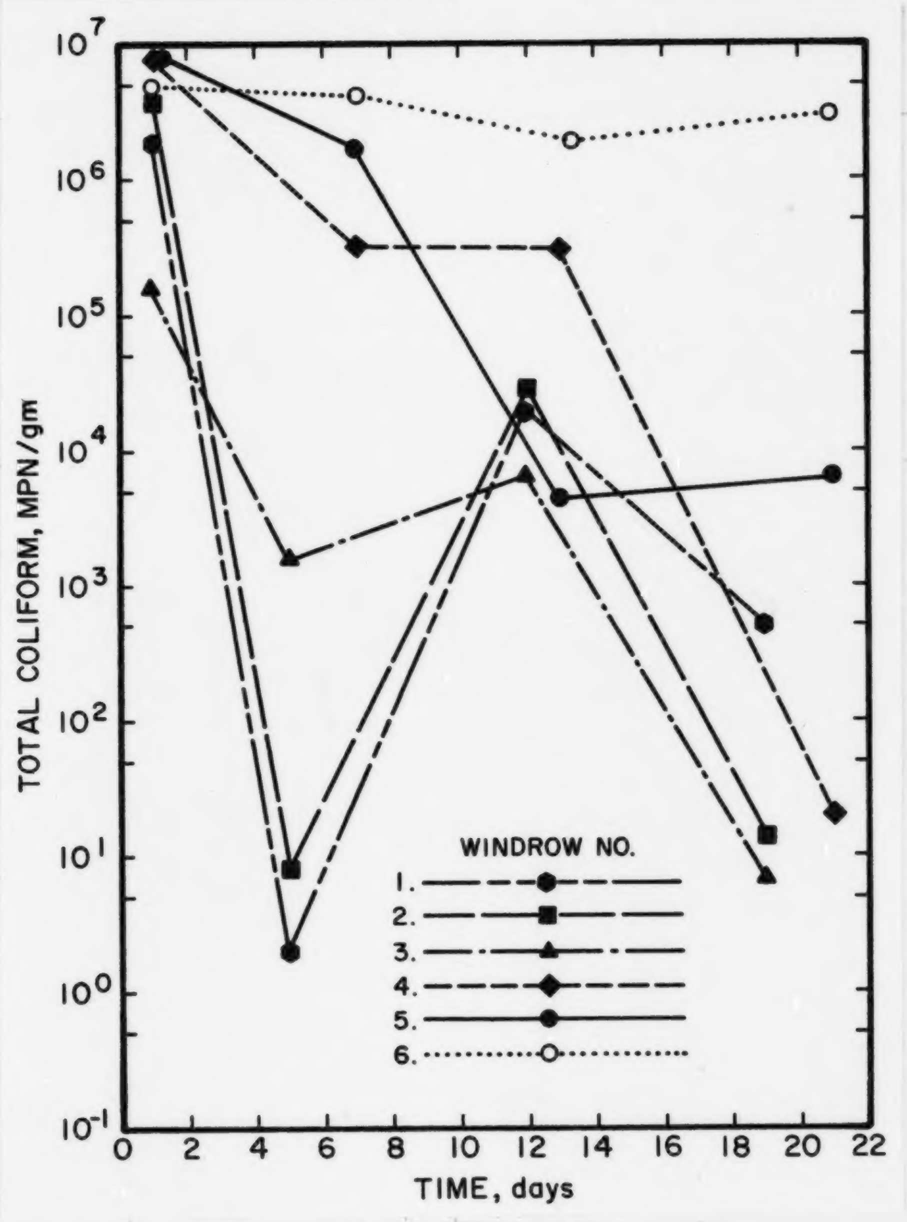

Figure 17. Total coliform data versus time for the windrows of Run 12.

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As shown in Table 18, average internal temperatures for the four windrows also varied according to the initial mixtures of wet and dry components. The initially dryer windrow (Windrow 4) exhibited the fastest temperature rise, achieving average internal temperatures in excess of 60°C (140°F) by day 8 of its cycle. This level was maintained for approximately 2 weeks. Windrow 3, the next driest, achieved elevated temperatures of 50°C to 55°C (122°F to 131°F) during the first week of its compost cycle, but average temperatures in excess of 60°C (140°F) were only recorded for one day. Temperatures for Windrow 2 remained above 50°C (122°F) from day 7 on, with the bulk of the temperatures being greater than 55°C (131°F). Windrows 1 and 2 both experienced lags in achieving elevated temperatures due to the greater proportions of sludge cake in these windrows. Both windrows showed gradual increases in daily temperatures until day 14, which was the first day of the 10 day period in which the windrows could not be turned. During this 10 day period, Windrows 3 and 4 maintained their elevated temperatures. Windrow 2 showed a slight increase in average temperatures during this period. Windrow 1, however, experienced a slight decline in average internal temperatures for the same 10 day period. Judging from the moisture contents of the windrows during this time, it appears that when turning is not practiced, elevated temperatures can be maintained only if a windrow is dry enough to allow for natural ventilation. Windrows 2, 3, and 4 had total solids contents on day 14 of 52%, 55%, and 60%, respectively, whereas Windrow 1, had a total solids content of 49% on day 14. The additional moisture present in Windrow 1 is thought to have caused the temperature decrease.

Microbiological data (Table 18) indicate that excellent microorganism kills were obtained in all windrows except Windrow 2. Note that the values for final total coliform levels are a geometric mean of three final samples, and in the case of Windrow 2, one sample contained less than 10 MPN/g while the others were in the 10^2 to 10^3 MPN/g range. The drier windrows performed more efficiently (less time needed) for inactivating microorganisms since high temperature elevations were more rapidly attained.

Significant Findings--Several conclusions can be drawn from the data given above and from the overall composting experience at the JWPCP involving the optimal percentage of recycled finished compost.

1. There is a large scatter in the data in Runs 12 and 16. In Run 12, the windrows with 0.8:1 and 0.4:1 ratios of finished compost to wet sludge cake did not compost nearly as well as the initially drier windrows. Drying times were about twice as long to reach 60% TS and final microorganism levels were above the desirable levels. However, in Run 16, the windrow with a 0.8:1 ratio achieved high temperature elevations and adequate pathogen kills. The variability in the data is caused by changing sludge characteristics with time, variable climatic conditions, and the difficulties in obtaining good quality control in the construction of the windrows.

2. Most of the research windrows studied have been constructed with a 0.8:1 ratio of finished compost to wet sludge cake and have produced acceptable results. However, full-scale plant operation at the JWPCP also uses the 0.8:1 ratio, and periodic monitoring has shown that, even though the windrows were drying at an acceptable rate, final microorganism levels during the beginning of Phase III were sometimes relatively high. This is due mostly to the fact that the construction of the research windrows is closely supervised by the project engineer and special efforts are made to assure proper operator attention to the windrows. Good mixing is emphasized to obtain the desired consistency, even at the low end of the proper working range. Given the difficulty in quality control during full scale plant operation, the variability in sludge consistency, and climatic conditions, higher recycle ratios of finished compost to wet cake may be necessary. About 1.3 m^3 of finished compost per metric ton of sludge cake (1.5 yd^3/short ton) is needed to assure that all portions of the windrows are within the proper working range.

3. From a materials handling standpoint, windrows constructed with ratios of 0.8:1 finished compost to wet sludge or higher are easily handled. Wetter windrows are difficult to turn and tend to slump and spread. An initial TS content of 45% or above is desirable for both easy handling and for immediate composting to begin.

Alternate Bulking Agents --

Recycled, finished compost may be used as a bulking agent in the composting of dewatered sludge. Bulking agents provide the desired initial TS content, allow for the structural stability of the windrow, increase the porosity for proper aeration and can also provide a source of carbon and seed bacteria. Bulking agents may also include external agents such as wood chips, sawdust, straw, rice hulls, wood shavings, etc. The purpose of the study on the use of bulking agents was to discover their effect on temperature elevation, pathogen inactivation and odor emission.

The majority of this report deals with composting that uses only recycled compost as a bulking agent. During later studies with deep windrows, alternate bulking agents (rice hulls and wood shavings) became available at no cost from the fertilizer company which processes JWPCP compost. The fertilizer company mixed in these additives with composted sludge to modify its products. Therefore, by supplying the Districts with these alternate bulking agents for mixing with the sludge prior to composting, this company saves one step in its processing of the compost. The possible advantages to the Districts noted during limited Phase II testing on alternate bulking agents included, 1) slightly improved composting performance due to the addition of the alternate bulking agents, 2) improved materials handling, since these alternate bulking agents were easier to mix with sludge than the recycled compost, 3) the texture and lower density of the windrows made turning easier and drying times shorter, and 4) stockpiling of finished compost for later recycle was not necessary.

Rune 19 (Figures 18 to 20) were conducted to investigate the extent of these advantages. Three deep windrows were constructed approximately 1.4 m

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(4.5 ft) high, 4.3 m (14 ft) wide and 45 m (150 ft) long. Windrow 1, the control windrow, consisted of 1.3 m^3 of finished compost per metric ton of wet sludge cake (1.5 yd^3/short ton). Windrow 2 and 3 were constructed in the same manner, except that instead of finished compost as the bulking agent, rice hulls and wood shavings were utilized, respectively, using a mixture of 0.84 m^3 of bulking agent per metric ton of sludge cake (1 yd^3/short ton). All windrows were turned three times per week throughout the cycle.

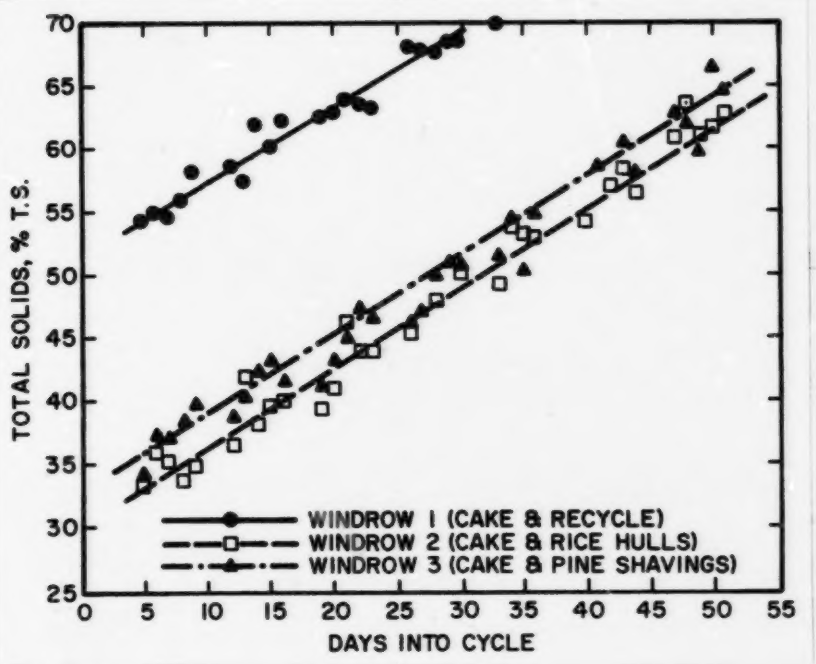

Figure 18. Total solids versus days into cycle for Windrows 1, 2 and 3 of Run 19

Performance results for the three windrows were as follows. It appears that the drying rates for the three windrows were similar (Figure 18). Since Windrow 1 was much drier at the start, it reached a level of 60% TS very quickly (15 days). Windrows 2 and 3 both exhibited identical total solids profiles throughout the compost cycle and they achieved 60% TS in 45 days. The increased time to reach the same level of dryness between Windrow 1 and the other two windrows can be attributed to the extra moisture within the starting mixtures for Windrows 2 and 3. The alternate bulking agent windrows were wetter at the start of the cycle than Windrow 1 due to the initial mixing procedure which blends set volumes of bulking agents with set tonnages of sludge cake. Rice hulls and wood shavings have substantially lower bulk densities than finished compost (Table 1), and thus contribute less dry material on a volume basis.

Visually, the alternative bulking agent windrows seemed to reach a finished (very fine) consistency much earlier in the compost cycle than 45 days. As of day 35, these windrows were of the same consistency as finished plant compost (60% TS) but were actually only 50 to 55% TS. Therefore, it may not be necessary to achieve the normal goal of 60% total solids within windrows which utilize the alternate bulking agents.

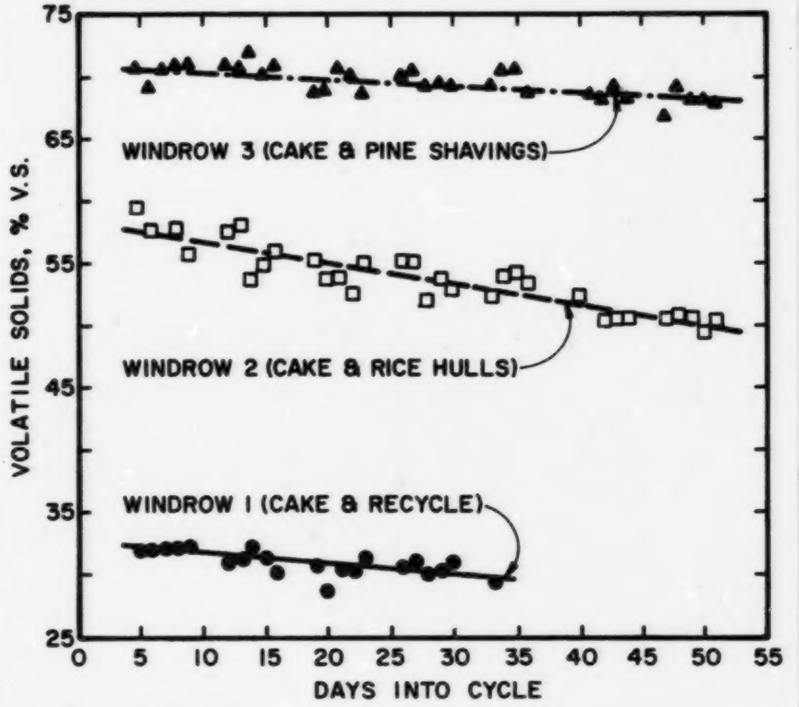

Figure 19. Volatile solids versus days into cycle for Windrows 1, 2 and 3 of Run 19.

All three windrows exhibited linear decreases in volatile solids content with time into the cycle (Figure 19). Windrow 2 showed a somewhat greater rate of volatile solids destruction than the other two windrows. Both Windrows 2 and 3 had higher levels of volatile solids (>50%) when the cycle was terminated. Based on volatile solids concentration (compared to earlier windrow results), these windrows apparently had not completed their composting cycles when the experiment was terminated after 53 days.

With respect to temperature elevation (Figure 20), all three windrows generated enough heat to achieve adequate bacterial inactivations. Windrows 2 and 3 were terminated with elevated temperatures of 60°C (140°F) and more than likely would have maintained these temperatures until either moisture or nutrients were lacking. By extrapolating the TS curves, it appears that the temperatures would have started to drop off if they had been left to compost 60 days or more. This increased amount of composting activity is a direct result of the addition of alternate bulking agents which are high in organic carbon.

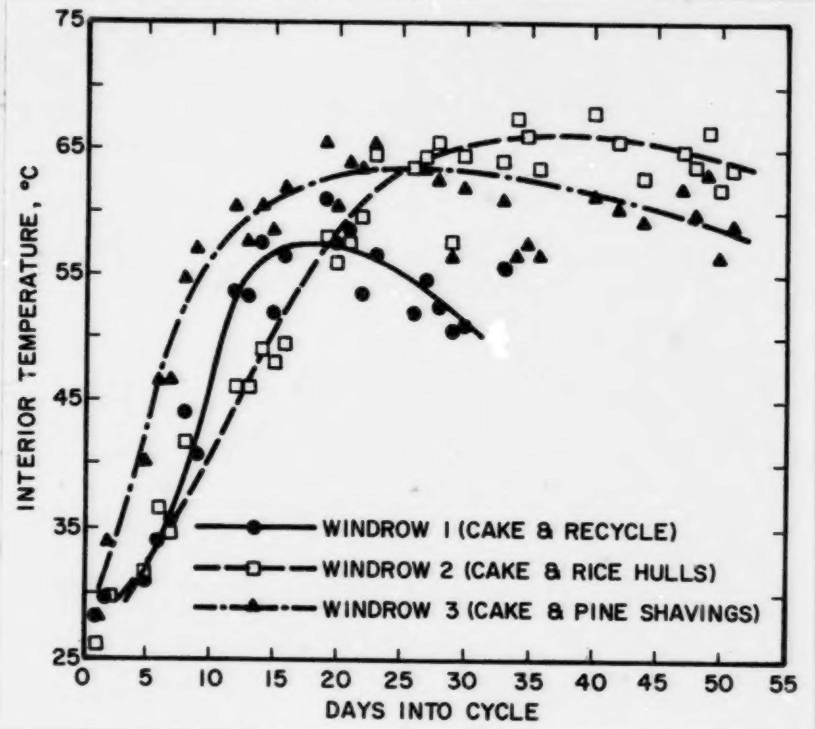

Figure 20. Interior temperature versus days into cycle for Windrows 1, 2 and 3 of Run 19.

Microbial samples collected routinely throughout the compost cycle of Test Run 19 indicate excellent inactivation of coliforms, salmonellae, and aspergilli. The minimum detection limit for these organisms was generally achieved in all windrows earlier in the compost cycle than in the final sampling. Thus the extended temperature elevations achieved may be of little benefit in terms of pathogen inactivation unless used as a method of controlling regrowth.

Final samples were taken in ten locations for each windrow as shown in Figure 21. Out of a total of 30 samples, only two were above 10 MPN/g for total and fecal coliforms. Windrow 2 and 3 samples were at the minimum detection limit for all of the organisms reported. Salmonella sp. and Aspergillus sp. were at the minimum detection limit for all of the 30 final samples. It was feared that the aspergilli might multiply in the windrows containing rice hulls and wood shavings, but this growth did not occur. Ascaris sp. ova were inactivated in all of the final samples collected (3 per windrow) for windrows 1 and 3. Windrow 2 samples which were collected at locations B, D and E (Figure 21) contained levels of viable Ascaris sp. ova of 0.6 OVA/g, <0.6 OVA/g and 0.6 OVA/g, respectively.

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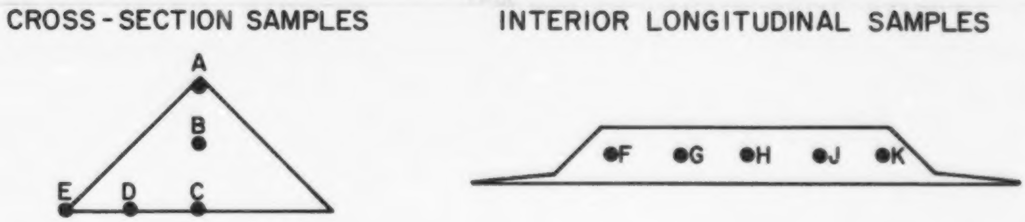

A TOP SURFACE SAMPLE

B INTERIOR SAMPLE

C,D,E GROUND LEVEL SAMPLES

F,G,H,J,K RANDOM INTERIOR SAMPLES

Figure 21. Final microbiological sampling locations for Windrows 1, 2 and 3 of Run 19.

In addition to the usual parameters monitored, analyses were performed during the latter half of the compost cycle to determine the carbon to nitrogen ratio (C/N) of the three windrows. The average C/N for Windrows 1, 2, and 3 were 15:1, 18:1, and 23:1, respectively. The C/N ratio of Windrow 1 is of particular interest because the majority of the literature states that a ratio of 20 to 25:1 is necessary to achieve adequate composting. Despite the very low 15:1 C/N ratio, Windrow 1 was able to achieve temperature elevations which were more than adequate for inactivation of all of the microorganisms tested.

Because the alternate bulking agents are being supplied at no cost, approximately 40% of the full-scale composting operation utilizes rice hulls and wood shavings instead of recycled compost. Although the data has shown that addition of alternate bulking agents does not necessarily improve composting performance, advantages of easier materials handling operations and possibly shorter drying times make the use of the alternate bulking agents attractive. (Drying times may be shorter due to the manageable compost consistency attained at 50 to 55% TS versus the norm of 60% desired when using recycled finished compost. This means less land area would be necessary for composting. Further research should be conducted to explore the possibility of removing the compost from the fields with a higher moisture content.)

Forced Aeration --

As part of the composting program conducted at the JWPCP, a study was initiated to investigate the composting characteristics of artifically aerated deep windrows (Run 14). Air was drawn through the windrows via a perforated piping system located 10 cm (4 in) below the ground level on one end of the windrow (Figure 22). The piping system was covered with wood chips and connected to an intermittently operating 5.7 m^3/min (200 cfm) blower. The windrows were turned once per day by means of the mechanical composter that is designed to accommodate the deeper windrows. The goals of the aeration study were to shorten the composting cycle and at the same time generate higher internal temperatures to insure an improved pathogen inactivation.

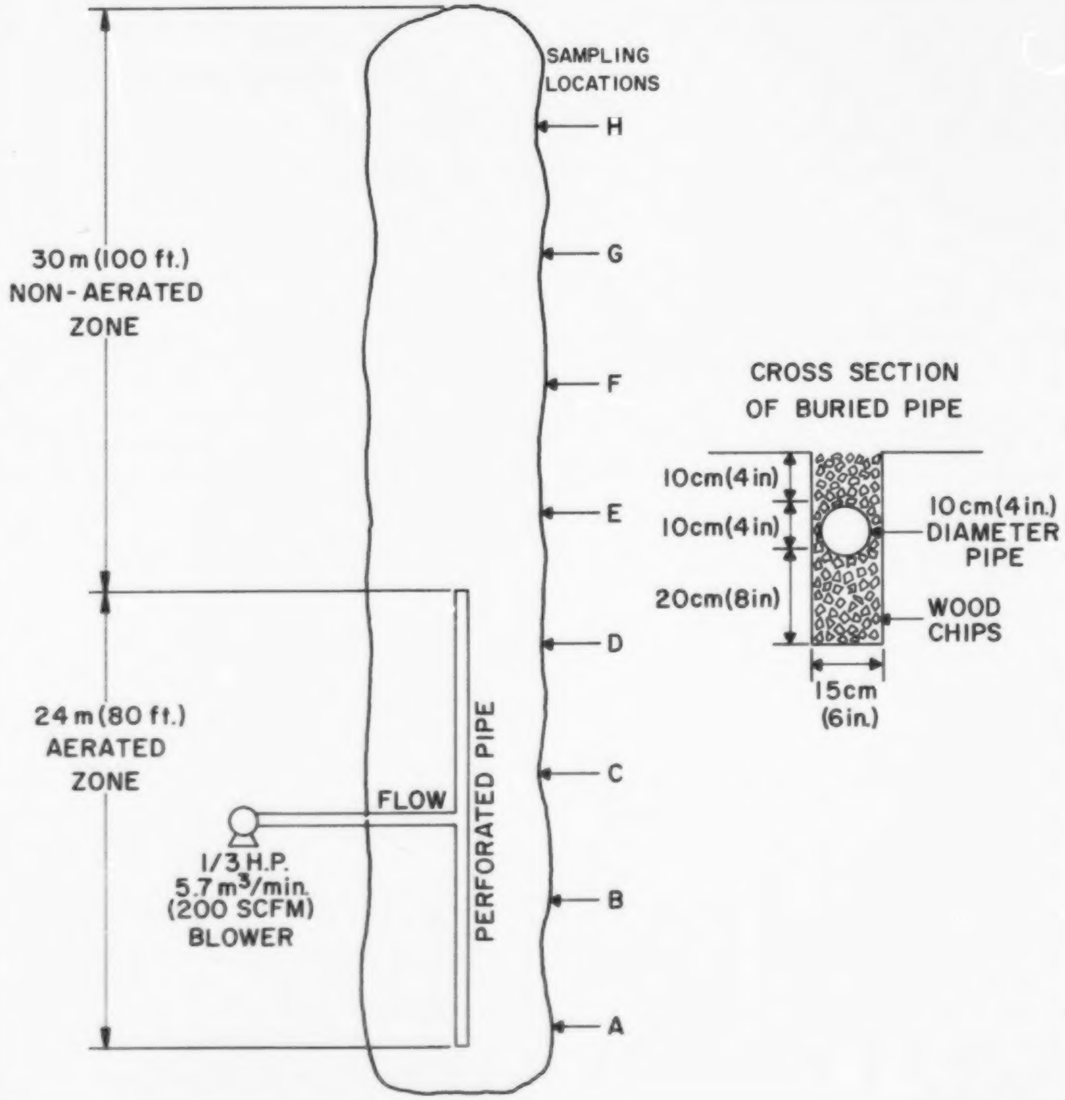
SAMPLING LOCATIONS
H
G
F
E
D
C
B
A
30m (100 ft.) NON-AERATED ZONE
24m (80 ft.) AERATED ZONE
FLOW
PERFORATED PIPE
1/3 H.P. 5.7 m³/min. (200 SCFM) BLOWER
CROSS SECTION OF BURIED PIPE
10cm(4in)
10cm(4in)
20cm(8in)
10cm(4in.) DIAMETER PIPE
WOOD CHIPS
15cm (6in.)

Figure 22. Schematic diagram of the JWPCP aerated windrow study.

After constructing two ventilation systems, a standard compost mix of approximately 40% TS was laid over system 1. The windrow was extended approximately 30 m (100 ft) beyond the perforated pipe to serve as the control or non-aerated zone. Two days later, a compost blend of 45% TS was placed over system 2, identical in windrow dimensions to system 1.

Temperatures were recorded at eight locations along each windrow, at depths of 0.3 to 1 m (1 to 3 ft). Data were averaged separately for the aerated and non-aerated zones. Figure 23 gives some representative temperature data from Windrow 1. Each point shown in the figure is the average of 12 individual windrow readings. The data indicate that forced aeration results in a faster temperature rise, but after 6 to 10 days, there is no difference in windrow temperatures. This temperature difference occurs only at the beginning of the compost cycle, whereas the maximum windrow temperatures needed for pathogen inactivation do not occur until the latter half of the compost cycle. At this later point in the compost cycle, forced aeration may cause lower temperatures, as seen in Figure 23.

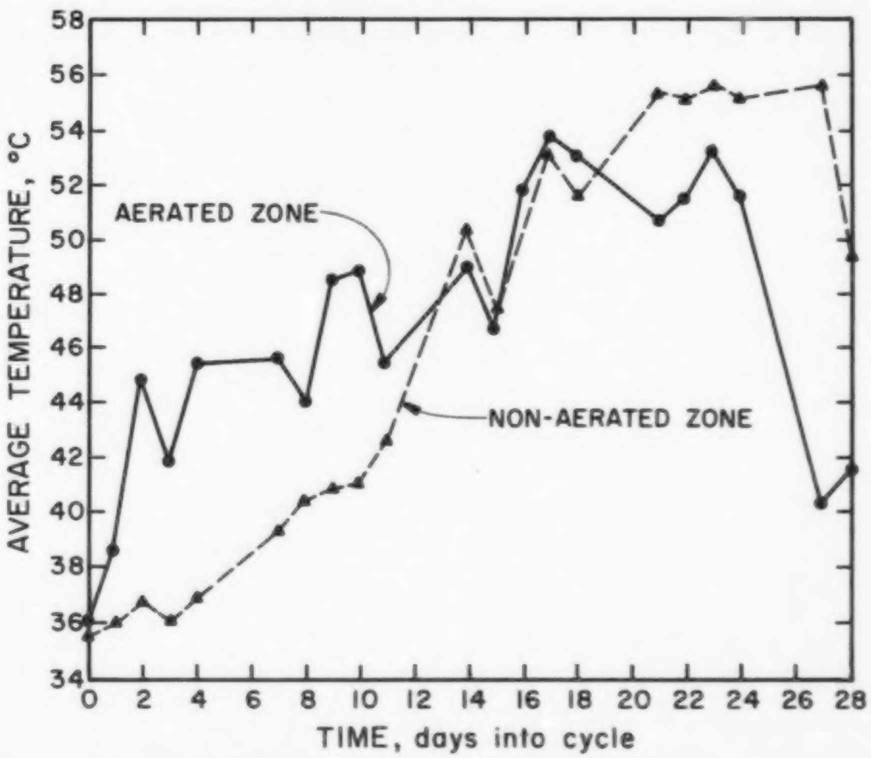

Figure 23. Average internal temperatures versus time for Windrow 1 of Run 14.

Neither of the windrows achieved an average temperature of 60^{o}C (140^{o}F). Windrow 1, non-aerated, maintained a temperature of 56^{o}C (133^{o}F) for six consecutive days. Windrow 2, non-aerated, had similar maximum temperatures.

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Drying and volatile solids characteristics are presented in Figure 24 for Windrow 1 (Windrow 2 profiles were similar). Little difference between aerated and non-aerated windrows was noted in terms of volatile solids destruction. Drying rates did seem to be slightly higher in the aerated zone. Windrow 1, starting at the normal plant mixture of 40% TS, is projected to take 30 days to reach 60% TS utilizing forced aeration. Windrow 2, starting at 45% TS, took 18 days to reach 60% TS. During the same time and weather conditions, the plant windrows took 35 to 40 days to reach final dryness (without forced aeration).

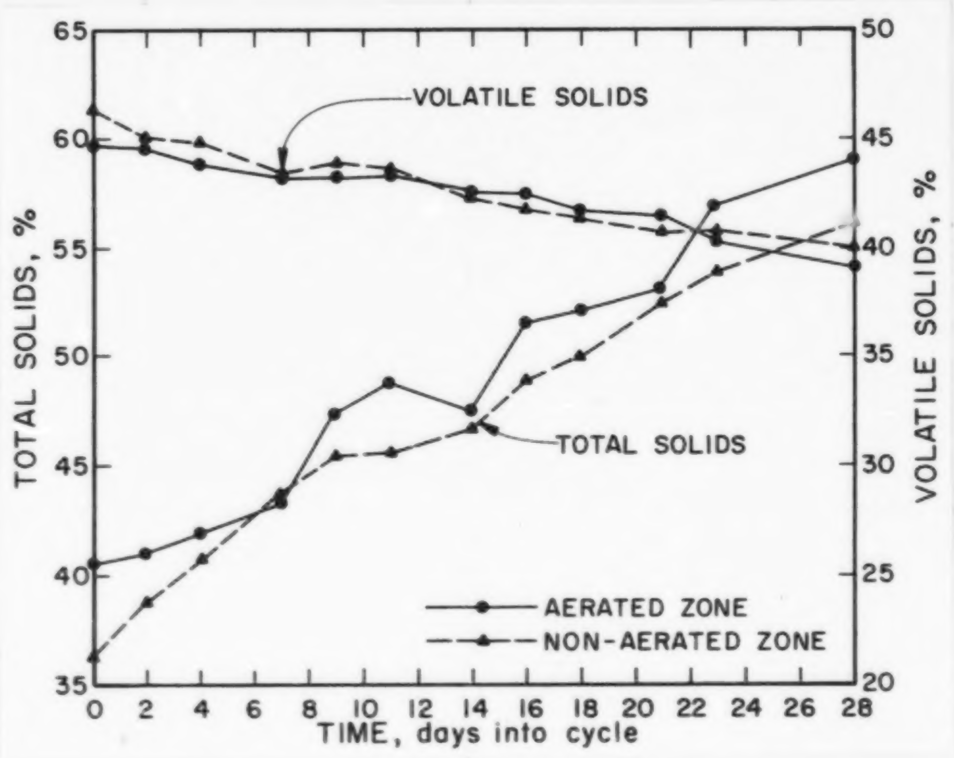

Figure 24. Total and volatile solids data versus time for Windrow 1 of Run 14.

Microbiological data were collected for Windrows 1 and 2. Results were poor for both windrows, in both the aerated and non-aerated sections. It is unclear why the levels of coliform, Salmonella sp. and Ascaris sp. ova were high in both sections of the windrows. No conclusions, therefore, can be made for pathogen inactivation within windrows utilizing forced aeration.

The air flow through the windrows averaged 6.7 m^3/min (200 cfm). Oxygen measurements were made both on the blower exhaust and inside the windrow. The on/off blower frequency was dictated by the presence of oxygen inside the windrow. Initially, the blowers were on half of the time, but this was more than what was needed for oxygen maintenance. A 15% on-time frequency (6 min on, 34 min off) was found to be adequate. After 6 min, the oxygen concentration in the blower exhaust reached steady state (18 -20% O_2) indicating that the voids in the windrow had been completely flushed with atmospheric air. It was also noted that excessive blower on-time lowered the windrow temperatures.

Based on these preliminary findings, forced aeration may result in faster drying times. This increased rate of drying is accomplished at the expense of temperature elevation. Use of forced aeration only at the beginning of the cycle would solve this, but would inevitably result in longer drying times than schemes utilizing forced aeration throughout the cycle. In terms of flexibility, a windrow composting operation with an aeration system may have benefits. More research is needed before any definite conclusions can be made about forced aeration of windrows.

Gaseous Oxygen Measurements --

A portable explosion meter and oxygen analyzer was used to measure the gaseous oxygen levels inside the actively composting research windrows of Run 13. In all cases, no oxygen was detected shortly after the windrow had been turned. It was believed, from theoretical calculations, that mere turning of the windrows did not provide sufficient oxygen within the voids created to maintain aerobic conditions in the windrows.

The windrows were not turned for the last 9 days of the cycle, and yet high temperatures and some drying activity did occur. Although no oxygen was detected in the windrows, composting activity (temperature elevation) was excellent. Thus, a special test was conducted. Two 1.2 m (4 ft) high piles of compost material were formed from a research windrow on day 20. Average temperatures were 60^{o}C (140^{o}F) and the TS content was 58%. One pile remained open to the atmosphere and the other pile was completely enclosed with a plastic sheet. The covered pile was purged with bottled nitrogen to quickly remove any oxygen. Both piles were monitored for temperature and gaseous oxygen. The temperature data recorded over the 8 day period are presented in Figure 25. No detectable oxygen was found in either pile.

The temperature data in Figure 25 indicate that the pile exposed to the atmosphere remained approximately 15^{o}C (27^{o}F) hotter than the covered pile. The covered pile temperature fell, after being covered, from 50^{o}C to 43^{o}C (122^{o}F to 109^{o}F), while the uncovered pile temperature rose from 52^{o}C to 62^{o}C (126^{o}F to 144^{o}F) in the same time period. It should be noted that at all times the covered pile temperature remained well above ambient temperature. After 145 hr, the plastic was removed from the covered pile. Temperatures began to rise immediately, and 40 hr later the pile temperature was 55^{o}C (131^{o}F).

Several conclusions can be formed from the results of these tests and observations of the unturned windrows. It appears that a natural movement of air occurs throughout the windrows and provides sufficient oxygen for composting. Field observations showed highest temperatures near the top of the windrows, and that heat can be generated in an anaerobic pile of compost. The covered compost pile did exhibit internal temperatures at least 13°C (23°F) higher than ambient after 6 days. The primary function of turning is not just to provide oxygen; turning is useful for drying the windrows and exposing all material to high temperatures.

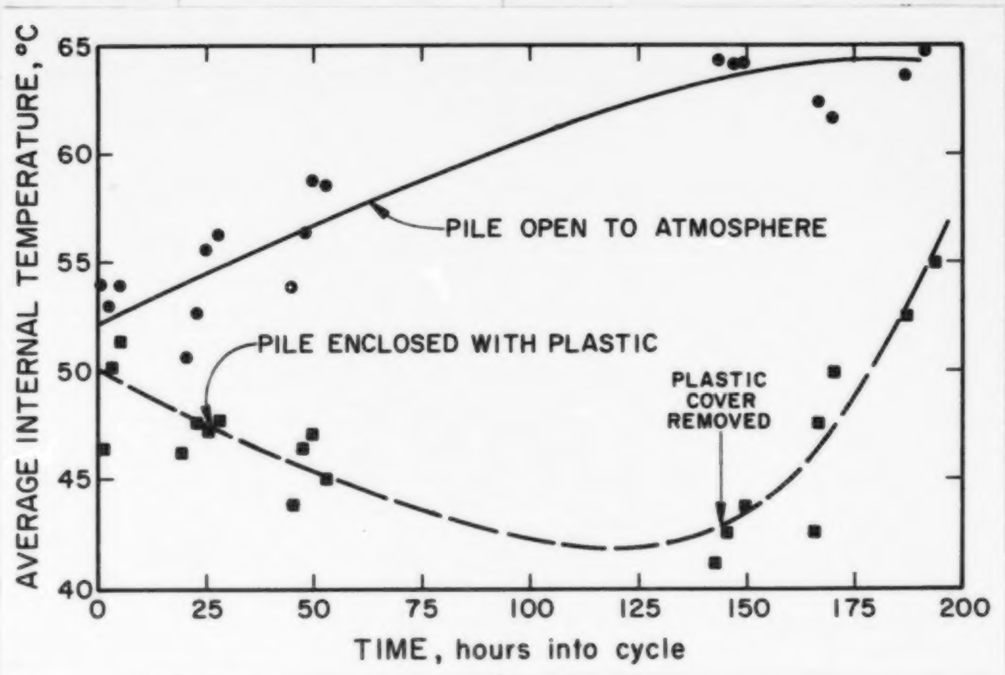

Figure 25. Average internal temperatures versus times for a covered compost pile.

Effects of Sunlight --

It has been suggested that the current sludge composting operation at the JWPCP could be improved if a building were placed over the entire composting area. This structure would serve two functions. The roof would shelter the area from winter rains which extend the compost cycle. The walls would provide for control of the odor and dust generated during the compost operation by blocking air movement. A potential disadvantage of a roofing structure is the reduction in compost drying rates due to the blocking of solar radiation or heat, assuming that the roofing material would be opaque to solar radiation.

Experimental Setup--In order to determine the quantitative effect of eliminating solar radiation on compost drying rates, a portable structure was built and covered with an opaque plastic sheeting (6 mil polyethylene impregnated with carbon black) as shown in Figure 26. The covering was made portable so that it could be manually removed and returned when the windrow was turned by the mechanical composter. To allow for adequate coverage of the windrow, two of the portable covers were employed and placed end to end over the windrow. In the design of the portable

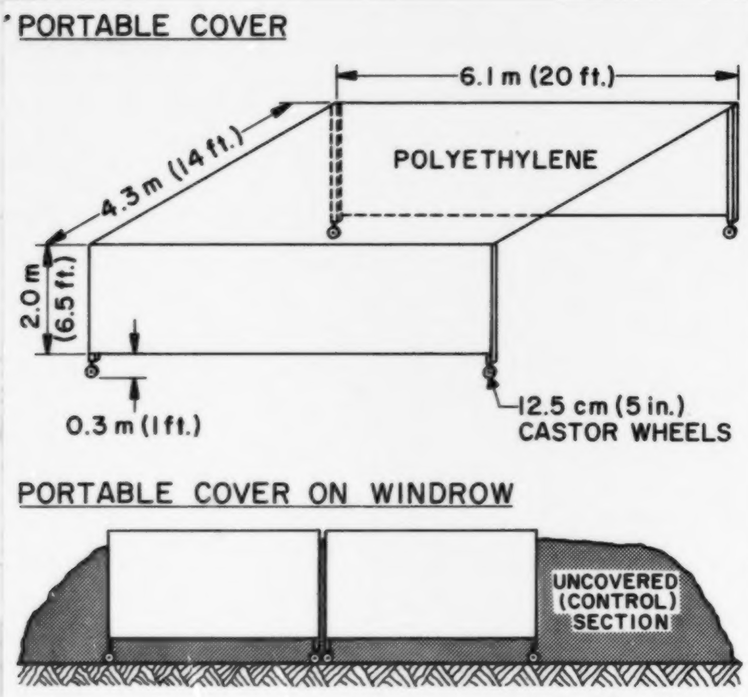

Figure 26. Schematic diagram of the JWPCP covered windrow study.

covering, a 0.3 m (1 ft) bottom clearance along the length was included to promote the free circulation of air inside the cover to avoid moisture build up. Thus, the study attempted to isolate the effect of solar radiation on windrow drying rates by maintaining the same weather conditions under the covers as those prevailing around the uncovered portion (control section) of the same windrow.

A deep windrow (from Run 15) was covered with the portable structures as shown in Figure 26. At the time of covering, the windrow was already 10 days into its compost cycle. Thus, no data were collected at the beginning of the compost cycle. The windrow was turned once per day.

Since the quantitative effect of solar radiation on drying rate could only be determined by comparing the respective TS data obtained from the covered and uncovered sections of the windrow, additional, comparable data were desired. To obtain this information, compost evaporation pans were filled with windrow compost and placed flush to the windrow surface. A total of four pans were constructed; two pans were placed on each side of the windrow for both the covered and uncovered sections. Two pans were required for each zone (covered and uncovered) in order to more truly represent the evaportion rate from both sides of the windrow surface. The procedure employed to obtain surface evaporation rates was as follows: immediately after the turning operation, the pans were refilled with windrow compost and weighed by means of a 27 kg (60 lb) top load balance.

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Afterwards, the pans were replaced flush to the windrow surface. The following morning, the pans were weighed again and the moisture loss recorded in kg of water/day/m^3.

Data recorded for both the covered and uncovered portions of the test windrow included: interior temperature, internal oxygen content, total and volatile solids, relative humidity, air temperature, and microorganism levels. No odor data were recorded.

Significant Findings--As presented in Figure 27, the total solids of both the covered and uncovered sections of the windrow slowly increased over the 21 day test period. If a compost water balance is made on the respective windrow sections using initial and final TS data, the following values are obtained:

	Experimental Results	Loss of Water
(Uncovered)	1 kg (2.2 lb) of compost at 47.5% TS drying to 60.0% TS	0.21 kg (0.46 lb)
(Covered)	1 kg (2.2 lb) of compost at 49.9% TS to 57.7% TS	0.16 kg (0.35 lb)

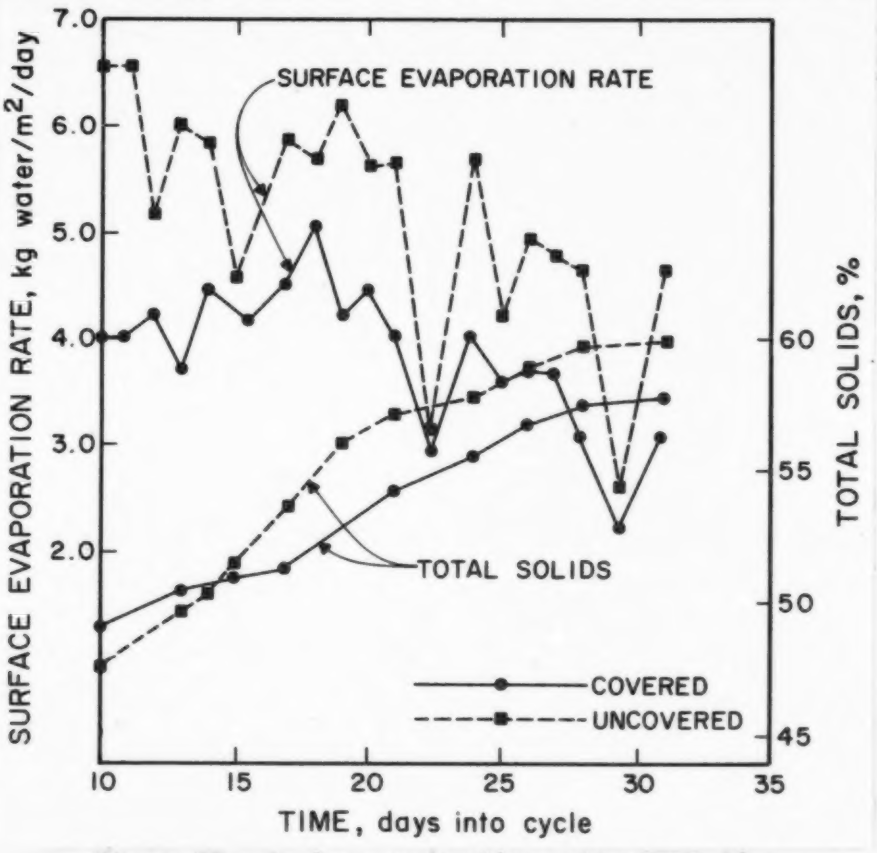

Figure 27. Surface evaporation rate versus time for the covered windrow study (Run 15).

Over the same cycle period, the average surface evaporation rates for the covered and uncovered sections, using the evaporation pan data, were 3.57 kg/day/m^2 (0.73 lb/day/ft^2) and 4.6 kg/day/m^2 (0.94 lb/day/ft^2), respectively. The data from the windrow and pan experiments were compared as indicated below:

TS data: 0.21/0.16 = 1.31 uncovered/covered

Pan data: 4.6/3.6 = 1.29 uncovered/covered

In comparing the respective ratio values of 1.29 and 1.31, it appears that the data are accurate and that the compost drying rates under an opaque covering will be approximately 24% less than those outside (no covering). Qualifications on the above value include:

a. the total solids range from approximately 47% to 60%;

b. the weather is typical of a summer condition at the JWPCP;

c. the windrow is approximately 1.2 m (4 ft) high.

The water loss phenomenon from a windrow is largely surface evaporation: when all the surface water is lost, diffusion of internal water to the surface becomes the controlling factor in further water loss. The air temperature and relative humidity were essentially the same underneath and outside the portable cover.

The interior temperature information obtained from the respective zones (Figure 28) indicates a consistently lower temperature in the covered section. This phenomenon can be explained by two mechanisms. The first is related to the windrow surface temperature. If, in the case of the uncovered windrow section, the surface temperature was higher than the covered section (due to the absorption of solar radiation), the heat loss from the interior to the surroundings would be less (Figures 14 and 15). The second mechanism is that the oxygen input into the windrow (which is needed for heat production) was less in the covered windrow due to the lower wind currents contacting the windrow surface.

The microorganism counts on the covered and uncovered sections of the windrow are presented in Table 19. Despite the lower interior temperatures of the covered windrow, acceptable inactivation of microorganisms was obtained in both the covered and uncovered sections of the windrow.

It appears that opaque coverings for the compost field will slow down the drying rate, but adequate composting should take place. Further research is desirable before plans for covering the compost field are adopted on a large scale.

TABLE 19. MICROORGANISM CONTENT OF FINISHED COMPOST FROM THE COVERED WINDROW STUDY (RUN 15)

WINDROW	SAMPLE NUMBER	TOTAL COLIFORM MPN/g	FECAL COLIFORM MPN/g	SALMONELLA sp. MPN/g	ASCARIS sp.	
					Total ova/g	Viable ova/g
Uncovered	1	<1	<1	<0.2	1.5	<0.2
	2	<1	<1	<0.2		
	3	<1	<1	<0.2		
Covered	1	<1	<1	0.2	0.8	1
	2	1	<1	<0.2		
	3	<1	<1	<0.2		

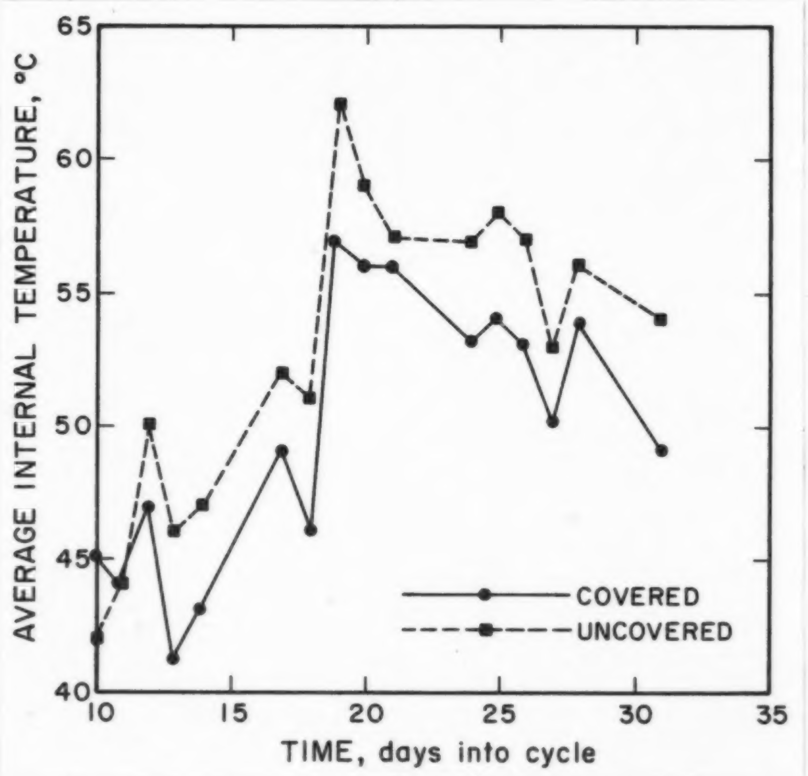

Figure 28. Average internal temperatures versus time for the covered windrow study (Run 15).

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Odor and Dust Control -

Because the JWPCP composting operation is located near a residential area, odor and dust control are of prime importance. In fact, odor and dust emissions now limit the amount of composting that is conducted at the JWPCP. As soon as odor and dust complaints are received and confirmed to be attributable to the composting operations, the composting operations are cut back until the complaints cease. Acceptability of odor and dust levels is a function of local wind and weather conditions and will vary considerably from month to month. The methods for collecting odor data were discussed in an earlier section. Data are collected in terms of odor dilution ratios within the samples and odorous emission rates per square foot of windrow surface area ($ft^3/min/ft^2$).

Odor investigations have been conducted at the JWPCP since 1977 when an increase in odor complaints from the community occurred, apparently the result of an increase in dewatered sludge production and a corresponding increase in odor emissions.

Factors Affecting Odor Emissions--Some general trends can be seen from the odor data collected over the past several years. It has become evident that the majority of odor emitted during the course of a compost cycle originates during the first 7 to 10 days. After this, the odorous emissions decrease significantly and level off at 0.2 to 0.3 $ft^3/min/ft^2$. A representative sample of these data is presented in Figure 29 for Runs 9 and 10. These observations suggest control of windrow turning in the beginning of the composting cycle.

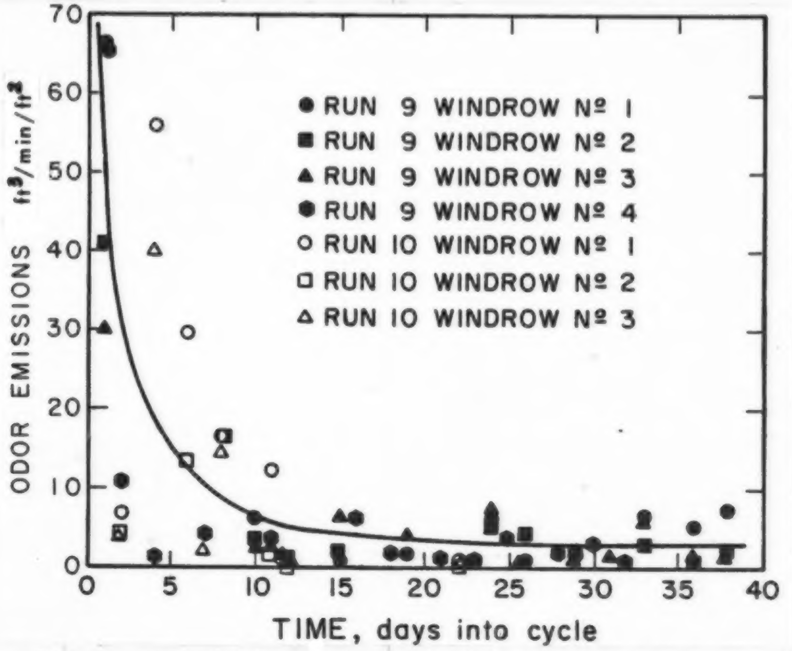

Figure 29. Ambient odor emissions versus time for the windrows of Runs 9 and 10.

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Another observation was that peak odor emissions occur immediately after turning of the windrows (Figure 30). This increase in odor emissions, due to turning, lasts for about 0.5 to 1 hr before ambient emissions are attained. To achieve better control of odors, turning could be halted during times of adverse meteorological conditions or during times of increased odor complaints. Turning might also be scheduled when local residents are less likely to detect odors (e.g., avoiding turning in the late afternoon when people are more likely to be home from work and outside.)

Though turning of the windrows may be associated with peak odor emissions, the majority of the total odor emitted comes from windrows in their unturned state. Data from Run 18 were used to determine the amounts of odor emitted and the percentage of odor emissions given off as a result of windrow turning. Table 20 presents data on odor emissions before and after turning for each of the six windrows of Run 18. From these data, the average odor emission rate per square foot of windrow surface area before turning was determined to be 0.5 $ft^3/min/ft^2$ (odor dilution ratios can be obtained by dividing the odorous emission rate by 0.17 ft^3/min, which is the flow rate supplied to the one square foot test box). Table 21 gives the amount of odor generated during a windrow composting cycle as a function of turning frequency. This analysis assumes that the compost cycle lasts 42 days and that the background odor emission rate for all windrows is 0.5 $ft^3/min/ft^2$. Peak odor emissions after turning were not assumed to be the same because they vary considerably as seen in Table 21. It appears that turning of the windrows accounts for between 10% and 15% of the total odor emitted from the compost cycle regardless of the turning frequency. Instantaneous odor emissions given off as a result of turning appear to be less intense for the windrows which were turned 5 days per week. The overall odor emission resulting from an increase in the number of turns during the compost cycle, however, is the same as windrows which are turned less often. Both the total and the peak odor emissions should be considered when evaluating odor problems in any given situation.

Methods of Odor Control--Several methods of odor control have been attempted on both a full-scale and a pilot-scale basis. Active composting areas were restricted to provide the maximum buffer zone possible with surrounding residential areas. The process of turning the windrows was also restricted to hours of greater vertical mixing in the atmosphere, between 8:00 A.M. and 4:00 P.M. The deep windrows now being investigated provide more sludge composting per land surface area and therefore provide a greater buffer zone between the composting operation and the neighborhood. A berm and block wall has been constructed along the boundary of the composting area of the JWPCP. Although this wall is intended to be a visual barrier it will induce some vertical mixing of odors in the atmosphere at the property boundary.

Another approach examined for odor control is the use of additives. Several manufacturers have products that claim to control sludge odors in general. One type of product masks or physically prevents release of odorous gases. Other products contain enzymes and bacterial cultures intended to aid in the metabolism of organic material, thereby controlling odors. A special test was conducted on a small scale to measure the effectiveness of two bacterial products. The tests were conducted to

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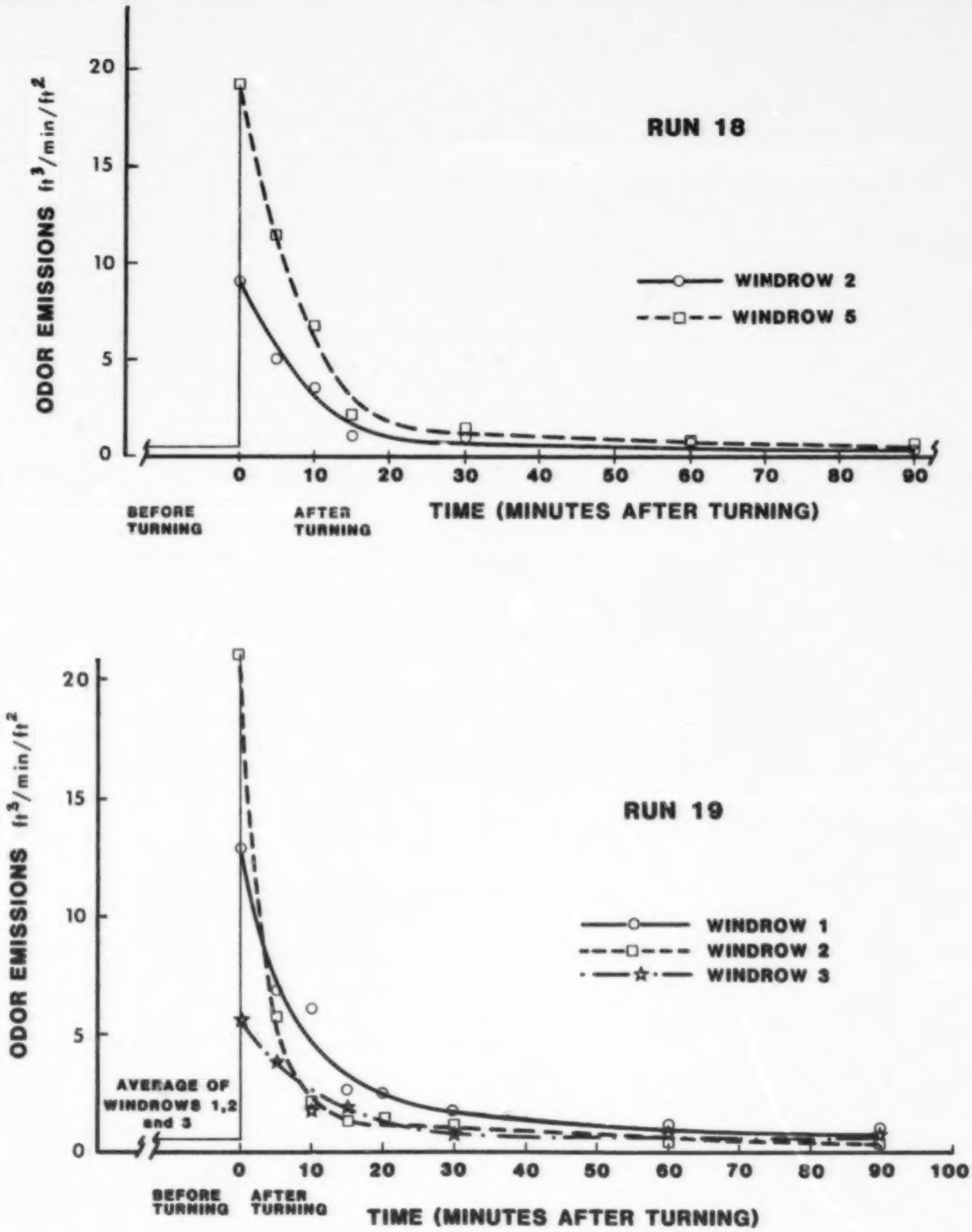

Figure 30. Average odor emissions as a function of time after turning.

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TABLE 20. SUMMARY OF ODOR EMISSION RATES FOR THE WINDROWS OF RUN 18*

Day of Cycle	WINDROW 1 Before	WINDROW 1 After	WINDROW 2 Before	WINDROW 2 After	WINDROW 3 Before	WINDROW 3 After	WINDROW 4 Before	WINDROW 4 After	WINDROW 5 Before	WINDROW 5 After	WINDROW 6 Before	WINDROW 6 After
	ODOR EMISSIONS $ft^3/min/ft^3$**											
2							0.2		2.2		1.67	
4	1.1		1.8		0.2							
5							0.3	8.2	1.0	0.9	0.2	2.0
7	0.3	2.7	1.0	6.0	0.5	8.2						
9							0.5	5.4	0.5	15.3	0.5	
11	0.5	8.5	1.0	6.3	0.3							
12							0.5	7.7	0.5	12.8	0.3	22.1
14	0.9	11.7	0.3	25.5	0.5	39.1	0.2	1.5	1.2	13.6	0.5	
16	0.5	9.4	0.2	5.1	0.5		0.5	21.3	Trace	38.3	0.5	
18	Trace	27.2	Trace	5.4	Trace							
19							0.3	5.4	0.5	15.2	Trace	6.8
21	0.3	2.0	0.3	24.7	0.5	30.6	Trace	1.0	0.5	5.3	0.3	
23	0.5	2.0	0.3	8.0	0.3		0.5	1.5	0.5	28.9	0.5	
25	0.5	5.4	0.5	8.5	0.5							
26							0.5	4.3	0.3	2.5	0.5	8.5
28	0.5	5.1	0.3	9.7	0.5	10.4	0.5	0.3	0.5	2.91	0.5	
30	0.5	8.0	1.4	13.6	0.5		0.2	2.2	0.5	5.1	0.5	
32	0.2	11.9	0.5	2.4	0.3							
33								0.5	0.3	4.1	0.5	2.1
35	0.5	8.6	0.5	20.4	0.5				0.5	16.2	0.2	
37			0.3	9.4	0.3				0.8	10.0	0.5	
39			0.5	2.9	0.3							
AVG.	0.5	8.6	0.6	10.6	0.5	22.1	0.5	5.4	0.6	12.2	0.5	8.3

* Odor samples were collected prior to turning and immediately afterwards for all windrows. except on days in which turning was not scheduled.

** Odor emission rate; cubic feed per minute per square foot of windrow surface area.

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TABLE 21. ODOR EMISSIONS ANALYSIS FOR THE WINDROWS OF RUN 18[a]

WINDROW NUMBER	AMBIENT[b] ODOR EMISSION ft^3/ft^2 (1)	ODOR EMISSIONS AS A RESULT OF TURNING				TOTAL ODOR EMISSION FOR COMPOST CYCLE ft^3/ft^2 (1) + (2)
		PEAK ODOR EMISSION RATE AFTER TURNING $ft^3/min/ft^2$	ODOR EMISSION PER TURN[c] ft^3/ft^2	NUMBER OF TURNS	TOTAL ODOR EMISSION GIVEN OFF AS A RESULT OF TURNING ft^3/ft^2 (2)	
1	30,240	8.6	129	30	3870	34,110
2	30,240	10.6	159	18	2862	33,102
3	30,240	22.1	332	12	3984	34,224
4	30,240	5.4	81	30	2430	32,670
5	30,240	12.2	183	18	3294	33,534
6	30,240	8.3	125	12	1500	31,740

[a] Assuming compost cycle last six weeks.

[b] Total background ambient odor emission for the windrow over the six week compost cycle assuming the ambient (background) odor emission rate from a windrow is 0.5 $ft^3/min/ft^2$.

[c] Odor emissions given off as a result of turning, assuming that the odor emissions after turning diminish uniformly from the maximum reading to the background level after 30 minutes.

simulate as closely as possible the conditions inside a windrow during the period of peak odor emissions.

Six buckets were filled with 17 kg (37.5 lbs) of compost material from a 4 day old JWPCP (plant) windrow. Two buckets were controls and received no additives; two buckets were dosed with a solid bacterial additive at the prescribed rate of 0.8 kg/m^3 (0.05 lb/ft^3); and the last two buckets were dosed with a second liquid bacterial additive at a dosage of 2.0 l/m^3 (0.02 gal/ft^3). The buckets were placed in a constant temperature water bath of 45°C(113°F) and were thoroughly mixed once per day. Immediately after mixing, odor samples were taken near the surface of the compost material. The samples were then taken to an odor panel for analysis.

Figure 31 contains the results of the odor panel analysis. The points shown on the graph represent an average of the odor level for each pair of identical buckets. Neither additive succeeded in lowering odor emission levels from the compost material and possibly the odor emission levels actually increased by the use of these products. During the 9 day test period, the material dried from 39% TS to roughly 45% TS. There was little change in the volatile solids content; all buckets remained at approximately 45% VS.

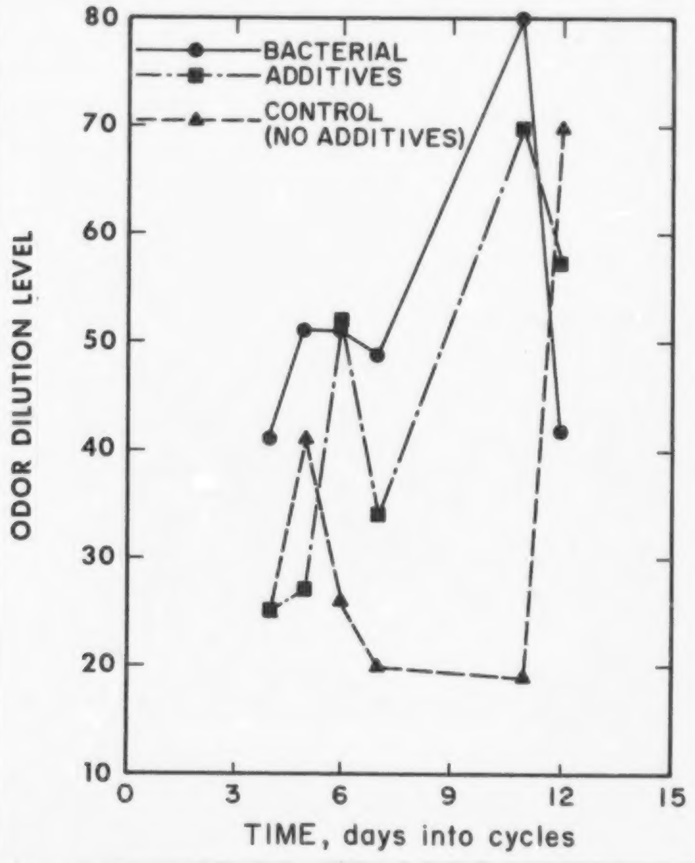

Figure 31. JWPCP small-scale study of odor control additives.

In addition to lab-scale testing, a study was made on the addition of one bacterial additive to a full-scale deep windrow. The dried inoculum was first dissolved in water at a concentration of 0.12 kg/l (1 lb/gal) and then applied to a newly constructed windrow by means of a pressurized sprayer. The solution was sprayed on the surface of the windrow at approximately 0.8 kg inoculum/m^3 (0.05 lb/ft^3) of wet centrifuge cake. Immediately after the surface application, the windrow was turned twice. Thereafter, the windrow was turned approximately once per·day until the compost cycle was complete. Since the level of odors emitted from the treated windrow were of primary importance to this study, three odor samples were taken every Monday, Wednesday, and Friday until the end of the compost cycle. A similar odor measurement schedule was conducted on a control windrow for comparative purposes. During the entire compost cycle of the inoculated windrow, interior temperature and oxygen measurements as well as TS and VS were taken on a routine basis. Similar measurements on the control windrow were also taken but only during the latter half of the compost cycle.

In examining the respective odor data plotted in Figure 32, it is obvious that the bacterial additive had no effect on reducing compost odors. In particular, no effect was observed during the critical (early) phase of the compost cycle when odor emissions are highest. No significant differences in compost variables such as gaseous oxygen, TS and VS were observed as a result of the bacterial additive, and therefore, no effects on the rate of composting were observed.

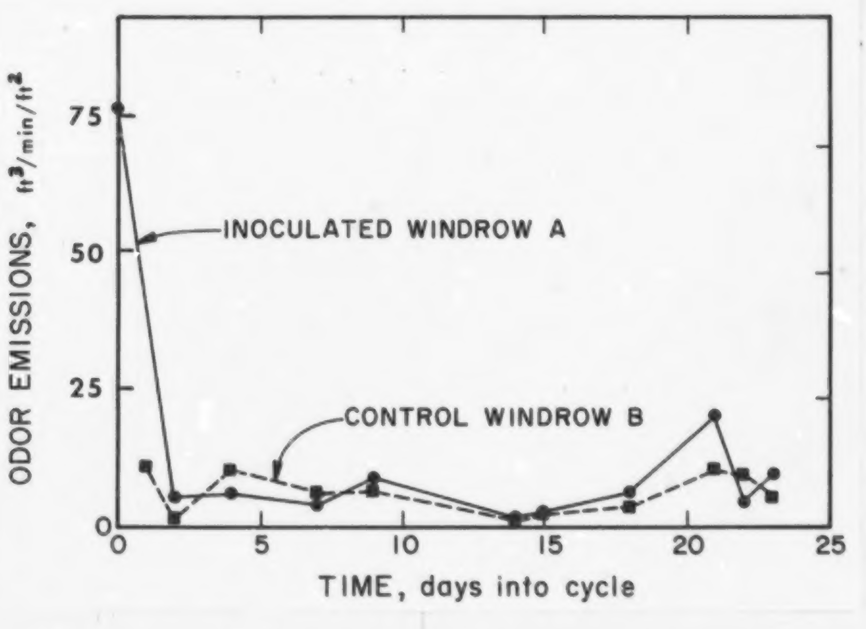

Figure 32. JWPCP full-scale study of odor control additives.

Dust Emissions--Another area of concern related to odor emissions is dust emissions. Neighbors have expressed concern over dust emitted from the compost field and it appears to have the same nuisance potential as odors. Airborne dust is emitted from the following components of the windrow compost operation.

1. pushing finished windrows into stockpiles
2. loading finished compost into trucks
3. turning dry windrows
4. vehicular traffic on fields, roads, and between windrows
5. action of strong winds on: stock piled compost, open fields and roads, dry compost at the end of and between windrows, and windrow surfaces.

It is not possible to accurately estimate the magnitude of these emission points. Suggested control techniques include a wide range of possibilities: water sprays (fixed or mobile), dust control chemical sprays, better housekeeping, timing of activities to coincide with low wind velocity, complete covering of the compost fields, and as a last resort, cessation of all composting. At this time, studies have been limited to the concept of spraying water or dust control chemicals. Small and full-scale studies were conducted using water and chemical crusting and wetting agents for dust control on the open fields. The wetting agents are intended to work by increasing the penetration of water into the compost fields. This is supposed to retard evaporation, and it is expected that the wetted fields will not dust. The crusting agents form a rigid crust upon evaporation of the water. However, neither chemical additive was found to reduce dust emissions to a greater extent than using water alone.

Monitoring of Airborne Aspergilli Spores --

A special study was conducted to identify and quantify the emission of *Aspergillus* sp. spores from the JWPCP compost field. An awareness of aspergilli came about because of the concern about a particular species, *Aspergillus fumigatus*, at the proposed compost facility at the Blue Plains Treatment Plant in Maryland. Aspergilli are commonly associated with decaying vegetation. The species, *Aspergillus fumigatus*, is classed as a secondary pathogen, being an opportunistic organism which has been known to infect individuals suffering from a variety of diseases including tuberculosis and silicosis. Spores of *A. fumigatus* are strong allergens to susceptible individuals.

Based on data already gathered, aspergilli spores were known to be present in the dewatered sludge cake but were substantially inactivated during the windrow composting process. The question of airborne *Aspergillus* sp. spores was investigated using an Anderson aerosol sampler. Both solids samples and air samples were taken at various stages of composting at the JWPCP. Typical levels of *Aspergillus* sp. within the sludge cake are 10^3 colony forming units per gram (CFU/g). The Anderson aerosol samplers distinguish between particles small enough to enter the lungs (respirable) and those that should be trapped in the nasal passages (non-respirable).

Based on the data presented in Table 22, the levels of airborne *Aspergillus* sp. appear to be rather low, both upwind and downwind of the operation. The highest single reading was 60 CFU/m^3. Literature sources suggest aspergilli levels of 500 CFU/m^3 are normal for ambient air. Samples were taken at locations where probable point-source emissions from compost operations might be taking place. Continued collection of data has indicated that levels remain low.

TABLE 22. AIRBORNE *ASPERGILLUS* SP. MONITORING PROGRAM

COMPOST OPERATION	SAMPLE LOCATION	*ASPERGILLUS* SP. CFU/m^3*	
		Respirable	Non-Respirable
Stockpiling Finished Windrows	Down Wind	<3	3
" " "	" "	2	0
" " "	" "	<1	<1
" " "	" "	<1	<1
" " "	Up Wind	<1	<1
" " "	" "	<1	<1
Adding Recycle to Wet Cake	Down Wind	7	60
" " " " "	" "	1	<1
" " " " "	" "	<1	<1
" " " " "	" "	<1	<1
" " " " "	" "	<1	<1
" " " " "	" "	<1	<1
Laying Windrow	Down Wind	4	<1
Turning Windrow	Down Wind	<1	<1
Windrow at Rest	Down Wind	7	19
Compost Field - Being Worked	Up Wind	<1	<1
" " " "	" "	<1	<1
" " " "	" "	3	1
Compost Field - Not Being Worked	Down Wind	31	33
" " " "	Up Wind	<1	<1

* CFU - colony forming units

Microorganism Regrowth in Finished Compost --

Concern has been voiced regarding regrowth of bacteria in finished compost. This is especially true for *Salmonella* sp. LACSD microbiologists have performed laboratory studies which indicate that if finished compost has a volatile solids content of less than 18% (dry weight basis), salmonellae bacteria may not regrow (5). However, a VS content of 18% is considered unrealistically low for a composting operation. A test therefore, was conducted to estimate the extent of *Salmonella* sp. regrowth in finished compost. Approximately 5 tons of finished compost from the Run 16 windrow cycle were rewet to 54% TS and formed into a 1.2 m (4 ft) high pile. This pile was not turned. Temperatures were recorded and samples routinely analyzed for total and volatile solids, total and fecal coliform, *Salmonella* sp. and *Aspergillus* sp. Results are presented in Table 23.

The results indicate that while there was some small increase in salmonellae levels during the first few days, the magnitude was quite small. Also, on the days that *Salmonella* sp. regrowth was observed, coliform numbers were very high. Considering the low number of organisms throughout the 14 day period, high levels observed on days 3 and 4 may not have been a regrowth phenomena, but simply unrepresentative sampling.

However, regrowth of pathogenic organisms within composted material may still be a possibility, and more studies are needed to develop operational techniques so that regrowth is not a problem.

TABLE 23. MICROORGANISM REGROWTH IN FINISHED COMPOST*

Days After Wetting	Temp. °C (°F)	TS %	VS %	BACTERIAL MPN/g Total Coliform	Fecal Coliform	*Salmonella* sp.	*Aspergillus* sp. CFU/g
Start	43 (109)	54	40	<0.5	<0.5	<0.2	<9
3	33 (91)	57	40	77,000	41,000	5	71
4	41 (106)	54	38	1,800	1,700	5.4	45
5	44 (111)	57	37	3.8	<0.5	<0.2	63
10	48 (118)	55	36	1.3	<0.5	<0.2	9
12	51 (124)	57	37	1.3	<0.5	<0.2	<9
14	54 (129)	64	31	<0.5	<0.5	<0.2	<9

* Material wetted and placed in a small pile.

Summary

Tables 24 through 26 present a representative summary of windrow composting results from the time the scroll and basket centrifuges were put into parallel operation (June 1978). No results are presented for Run 12 since this run was conducted as a trial run to familiarize new personnel with composting operations. Runs 14 and 15 are not included since only limited data were collected. Some significant observations can be drawn from the data presented in Tables 24 through 26.

1. Even though there was a variation in windrow size, cycle time, initial moisture content, turning frequency, percent recycle of finished compost, alternative bulking agents, etc., the finished compost material contained virtually no pathogenic organisms and only trace amounts of coliform organisms in each of the experiments (Table 26).

2. The temperature data in Table 24 indicate that the windrows varied in exposure time above 55°C (131°F) from 4 to 34 days. However, all of these durations were adequate for pathogen inactivation.

TABLE 24. SUMMARY OF TEMPERATURE DATA FOR PHASE III WINDROW CYCLES

Run	Windrow	Duration Of Cycle (Days)	Number of Days Internal Temperature Exceeded 50°C (122°F)	Number of Days Internal Temperature Exceeded 55°C (131°F)	Number of Turns When Temperature Exceeded 50°C (122°F)	Number of Turns When Temperature Exceeded 55°C (131°F)
13	1	27	14	8	-	-
	2	27	17	13	-	-
16	1	42	23	16	8	7
	2	40	22	13	6	4
	3	36	28	16	6	2
	4	34	28	22	9	8
17	1	44	22	9	9	2
	2	44	24	15	7	5
	3	44	22	12	5	2
	4	44	19	10	7	3
	5	44	22	10	9	3
	6	44	24	14	8	3
	7	44	26	9	6	1
	8	44	25	16	9	3
18	1	35	17	4	12	4
	2	38	18	7	9	4
	3	42	27	21	7	6
	4	33	18	11	14	8
	5	36	23	14	10	7
	6	40	27	23	8	7
19	1	32	22	12	9	5
	2	50	37	34	16	15
	3	50	44	42	19	18

TABLE 25. SUMMARY OF VIABLE *ASCARIS* SP. DATA FOR PHASE III WINDROW CYCLES

Run #	Windrow #	Number of Samples	Number of Samples With Detectable ova	Viable *Ascaris** sp. ova/g
16	1	3	0	<0.4
	2	3	0	<0.4
	3	3	0	<0.6
	4	3	1	<0.3 - 0.3
17	1	6	0	<0.6
	2	1	0	<0.4
	3	6	0	<0.5
	4	1	0	<0.7
	5	7	2	<0.4 - 1.8
	6	1	0	<0.5
	7	7	2	<0.3 - 0.9
	8	2	0	<0.9
19	1	3	0	<0.4
	2	3	2	<0.6 - 0.6
	3	3	0	<0.5

* Dewatered Sludge typically contains 5-10 viable *Ascaris* sp. ova per gram.

3. The eggs of the roundworm, *Ascaris* sp., were selected for monitoring the degree of parasite inactivation. The parasite data in Table 25 for 15 windrows represent the results from separate grab samples of finished compost. Twelve of the samples were taken from the very bottom of Windrows 1, 3, and 7 of Run 17, a location that experience has shown is likely to have the highest pathogen counts. Only 7 out of 52 samples contained any detectable viable ova. No viable ova were detected in the remaining samples. Excellent inactivation of *Ascaris* sp. ova was achieved.

Results from the Phase III windrows indicate that operational parameters can be varied widely without adversely affecting performance. However, even though these research windrows all performed well, it is these windrows that receive the most operator attention. The initial mixtures are very carefully controlled, turning is done regularly, and sampling is carefully conducted. Composting operations that are not as well managed may not perform as well.

TABLE 26. SUMMARY OF BACTERIAL DATA FOR PHASE III WINDROW CYCLES

Run #	Windrow #	Number of Final Samples	FINAL BACTERIAL LEVELS* Total Coliform (MPN/g)	Fecal Coliform (MPN/g)	Salmonella sp. (MPN/g)
13	1	2	<0.5	<0.5	<0.2
	2	2	0.6	<0.5	<0.2
16	1	3	0.7	<0.5	<0.2
	2	3	1.0	<0.5	<0.2
	3	3	0.8	<0.5	<0.2
	4	3	0.8	<0.5	<0.2
17	1	7	3.5	1.2	<0.2
	2	2	0.6	<0.5	<0.2
	3	7	2.0	1.4	<0.2
	4	2	0.8	0.8	<0.2
	5	7	4.1	2.9	0.2
	6	2	3.4	1.1	<0.2
	7	7	0.6	0.6	<0.2
	8	2	32	32	<0.2
18	1	8	21	6	<0.2
	2	8	11	4	0.4
	3	8	1.5	1.1	<0.2
	4	8	21	7	0.2
	5	8	13	3	<0.2
	6	8	4	2	<0.2
19	1	10	<0.4	<0.4	<0.2
	2	10	<0.5	<0.5	<0.2
	3	10	<0.5	<0.5	<0.2

* Reported values are geometric means

Enough data were available to produce bacterial die-off curves for each of 20 windrows (Runs 13, 16, 17, and 18). The number of days of interior windrow temperatures above 55°C (131°F) required to reach a specified organism level were then determined. The data were ranked from the least number of days to the greatest number of days, and plotted on probability paper with curves drawn to fit the data. In Figures 33, 34, and 35 tne ordinate corresponds to the percentage of windrows which achieved the specified organism content as a function of the number of days in which the interior windrow temperature exceeded 55°C. Figures 33 and 34 indicate that approximately 7 days at 55°C (131°F) were required for 80% of the windrows to measure 10 MPN/g of coliform or less in the compost material; approximately 60% of the windrows measured 1 MPN/g of coliform or less. For Salmonella sp., 85% of the windrows had less than 0.2 MPN/g (Figure 35) for a 7 day period in which temperatures exceeded 55°C. To help insure these microorganism kills, a turning frequency of at least twice per week should be used.

Some pathogen inactivation occurs in the windrows before reaching 55°C (131°F) temperatures. Typical of a windrow compost cycle, the internal temperatures rise slowly before reaching a plateau level in the 55 to 60°C (131 to 140°F) range. Figures 36, 37 and 38 are probability plots showing the number of days above 50°C (122°F) needed to achieve the indicated microorganism levels. After 5 days exposure to 50°C (122°F) temperatures, 40% of the test windrows had coliform levels less than 10 MPN/g and salmonellae levels less than 0.2 MPN/g. These results appear to indicate the capability of the windrow composting process to achieve good temperature elevations and consistent pathogen inactivation.

The windrow composting research has resulted in several options for improving full-scale windrow composting at the JWPCP with respect to temperature elevation and microorganism kills. Studies have shown the relative importance of windrow size (deep versus shallow windrows), turning frequency, and percentage of finished compost material and the effects of less important parameters (e.g., recycle material, forced aeration, etc.). The data on microorganism inactivation indicates that adequate performance can be obtained with a wide range of operational parameters.

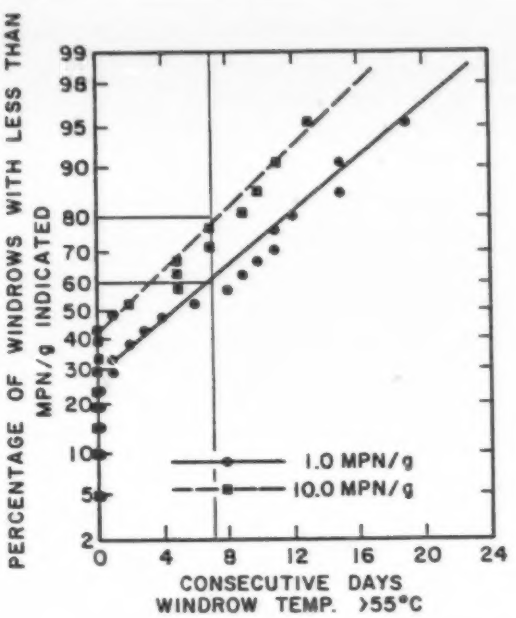

Figure 33. Summary of total coliform inactivation at $55^{0}C$ for Phase III windrows cycles.

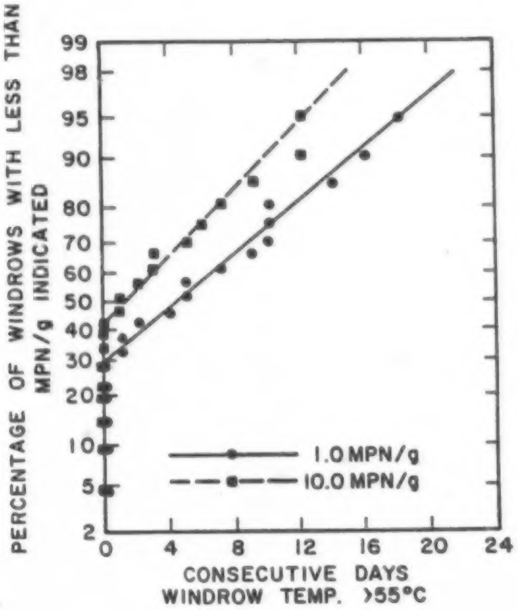

Figure 34. Summary of fecal coliform inactivation at $55^{0}C$ for Phase III windrow cycles.

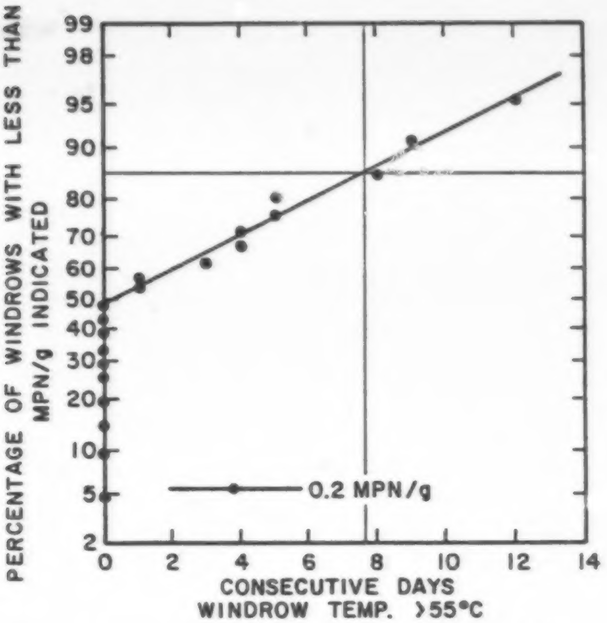

Figure 35. Summary of salmonellae inactivation at 55^{0}C for Phase III windrow cycles.

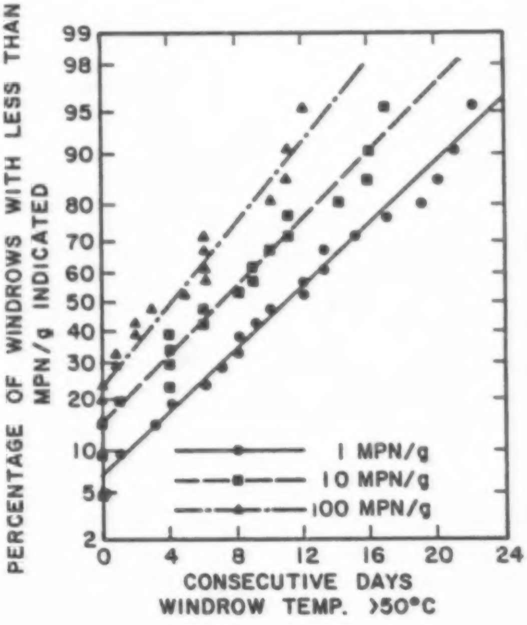

Figure 36. Summary of total coliform inactivation at 50^{0}C for Phase III windrow cycles.

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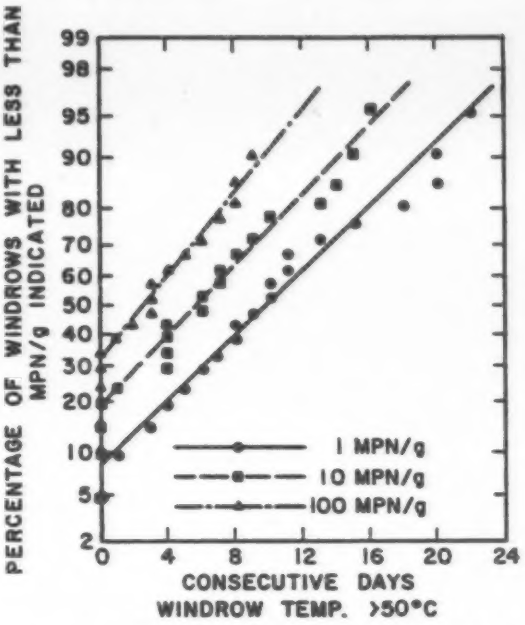

Figure 37. Summary of fecal coliform inactivation at 50°C for Phase III windrow cycles.

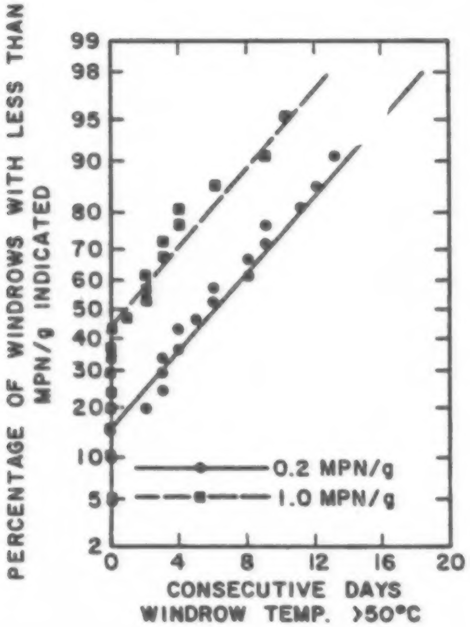

Figure 38. Summary of salmonellae inactivation at 50°C for Phase III windrow cycles.

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SECTION 4

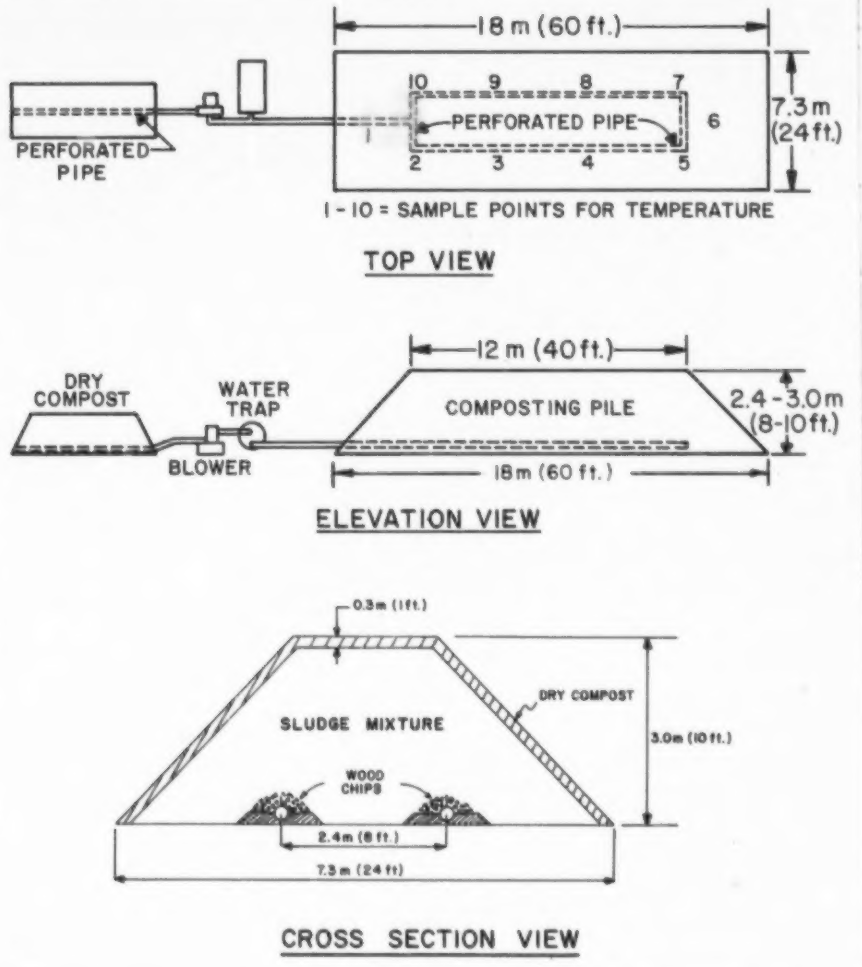
STATIC PILE COMPOSTING

INTRODUCTION

Experiments on static pile composting similar to the process developed in Beltsville, Md. (7), were conducted at the JWPCP from November 1977 through July 1978. The schematic of a static pile is presented in Figure 39. The piles tested were typically about 18 m (60 ft) long, 7.3 m (24 ft) wide, and 2.4 to 3.0 m (8 to 10 ft) high. They were constructed using a front end loader to pile sludge from windrows which were previously formed and mixed with the desired quantities of sludge cake and finished compost. Static piles are aerated in order to assure aerobic conditions and to assist in odor control. Air is either blown or drawn through the piles using the perforated piping system shown in Figure 39 which is 10 cm (4 in) in diameter with 1.5 cm (0.6 in) perforations. In these experiments air was drawn through the piles. A 1/3 HP blower was used for aeration and a water trap was used to protect the blower when operated in the vacuum mode. The blower was operated on an intermittent basis and air flow was measured using a 10 cm (4 in) annubar. Wood chips were placed on the perforated piping to help prevent clogging. After the pile was constructed, 0.3 m (1 ft) of finished compost was then added to the top of the pile for heat and odor insulation. Recycled finished compost was the only bulking and moisture control agent used, except where noted. Wood chips were not used as a bulking agent in these experiments since they are expensive and their use results in an additional step (screening) in the operation.

Three successful runs were made using static piles during the time period from November 1977 through July 1978. Questions of interest included 1) the need for alternate bulking agents other than recycled finished compost, 2) the amount of odors emanating from the piles and from the blower exhaust, 3) the possibility of anaerobic zones throughout the pile, 4) percentage by volume of bulking agent required, and 5) the amount of drying which will take place in a static pile. As with all composting performance, the main parameters for evaluating this process were temperature elevation and microorganism inactivation.

The static pile process offers some possible advantages over windrow composting, though most were not realized during these investigations. At the time odors were of prime concern since the JWPCP is located near residential areas. Because no turning is employed as with windrows and less surface area is exposed due to the geometry of the pile, static piles were expected to produce less odors. Also, the odors from the static piles may be easier to control since the major source of odors, the blower, is a point source. Another advantage is the use of less land for static pile composting. However, if the sludge had to be laid in windrows for further drying after composting, this advantage would be erased.


18 m (60 ft.)
10
9
8
7
PERFORATED PIPE
6
1
2
3
4
5
7.3 m (24 ft.)
PERFORATED PIPE
1 - 10 = SAMPLE POINTS FOR TEMPERATURE
12 m (40 ft.)
DRY COMPOST
WATER TRAP
COMPOSTING PILE
2.4 - 3.0 m (8-10 ft.)
BLOWER
18 m (60 ft.)
0.3m (1 ft.)
DRY COMPOST
SLUDGE MIXTURE
3.0m (10 ft.)
WOOD CHIPS
2.4 m (8 ft.)
7.3 m (24 ft)

TOP VIEW

ELEVATION VIEW

CROSS SECTION VIEW

Figure 39. Schematic diagram of the JWPCP aerated static pile.

RESULTS

Several operational parameters were studied as to their effects on static pile composting performance. Each run was used to investigate an operational parameter of importance. A summary of the runs made and their purpose is presented below in Table 27.

TABLE 27. STATIC PILE COMPOSTING RESEARCH SUMMARY

Run	Starting Date	Number of Piles	Parameters Evaluated
1	11/8/77	3	Alternate Bulking Agents, Odors
2	4/10/78	5	Extended Piles, Use of Recycled Compost Only, Odors
3	6/20/78	4	Percent Recycle of Finished Compost, Odors

Alternate Bulking Agents

Run 1 consisted of three static piles utilizing different bulking agents. Pile 1 consisted of 0.84 m^3 of finished compost per metric ton of sludge cake (1 yd^3/short ton) with an additional 0.84 m^3 of rice hulls. Pile 2 consisted of the same mixture ratio as Pile 1, but with wood shavings instead of rice hulls. Pile 3 consisted of 1.7 m^3 of finished compost per metric ton of sludge cake (2 yd^3/short ton) with no additional bulking agents added. The piles were built on three consecutive days. Air was drawn through the piles utilizing a 25% on-time for the blower (5 minutes on and 15 minutes off) until day 27 of the cycle. Thereafter the blower was operated with a 50% on-time.

Temperature data was collected daily at a total of 10 points throughout each of the piles. Average daily temperatures for the three piles are presented in Figure 40. The temperature rise for each pile was rapid during the first 10 days of operation and remained somewhat constant until 30 days into the cycle at which point the temperature began to drop. Pile 2 exhibited the highest temperature, being slightly higher than Pile 1. Inspection of the temperature data indicates that Pile 3 did not perform as well. Average temperatures were lower than for Piles 1 and 2. The range in temperatures within the pile was also greater than for Piles 1 and 2, indicating that the addition of carbonaceous bulking agents resulted in higher internal temperatures and hence a higher level of composting activity. However, it is important to note that elevated temperatures were achieved in all three piles. Typically, temperatures above 55°C (131°F) for several consecutive days are sufficient to produce adequate microorganism kills. All three piles experienced temperatures above 55°C (131°F) for over 30 days.

Very little odor emanated from the surface of these piles. The surface was essentially odor free after day 10 of the cycle (the amount of surface odor emitted was approximately the same for both windrows and static piles). The odor level of the exhaust, however, was considerable and must be handled accordingly. The exhaust from Piles 1 and 2 contained a higher concentration of odor in the exhaust than Pile 3, but the exhaust from Pile 3 was considered a much more offensive odor. The present odor test utilizes an odor panel, and only detection limits are determined; offensiveness of the odors are not measured. Odor data collected during

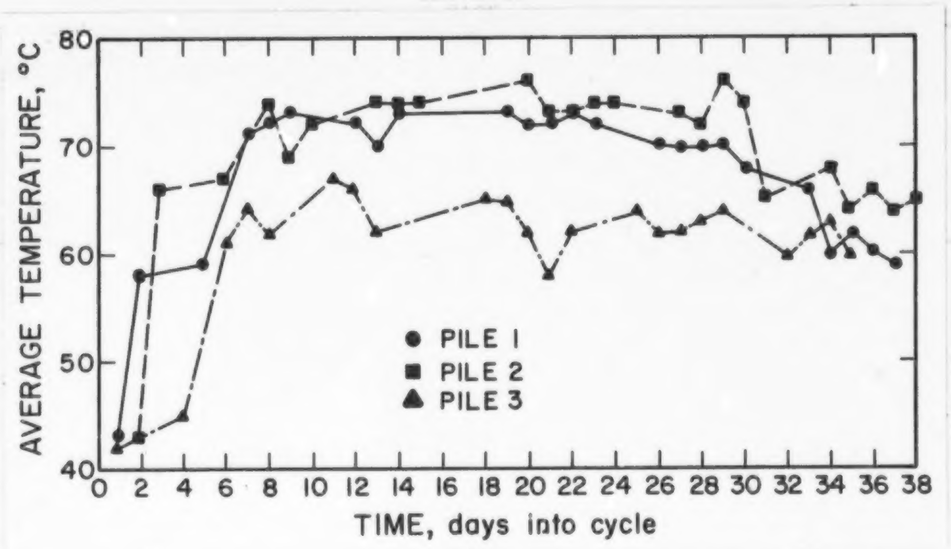


Figure 40. Average temperatures versus time for the static piles of Run 1.

removal of the piles indicate that the amount of odors given off at this time can be quite high.

Coliform and salmonellae data (Table 28) reveal that excellent inactivation was experienced within the piles in as little as 10 days for Piles 1 and 2, and in 18 days for Pile 3. Data collected during dismantling of the piles (Table 29 and Figure 41) showed very low levels of total and fecal coliforms and Salmonella sp. The only sign of contamination was in the top surface cover of the three piles, but even these values were all lower than those taken at the start-up of the piles.

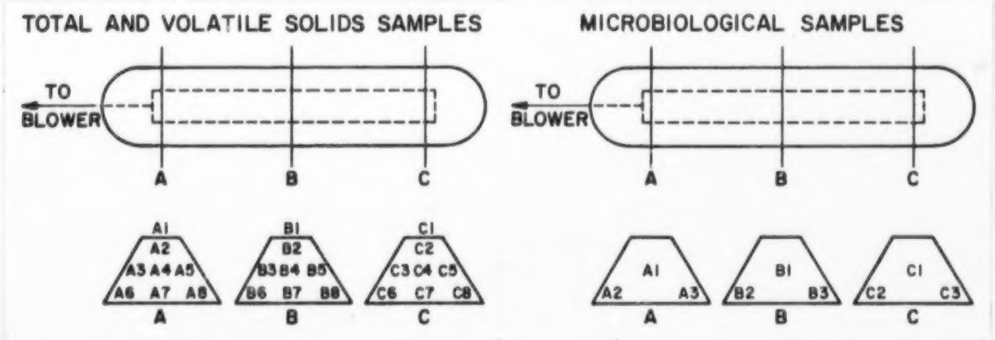

TOTAL AND VOLATILE SOLIDS SAMPLES
MICROBIOLOGICAL SAMPLES
TO BLOWER
TO BLOWER
A
B
C
A
B
C
A1 A2 A3 A4 A5 A6 A7 A8
B1 B2 B3 B4 B5 B6 B7 B8
C1 C2 C3 C4 C5 C6 C7 C8
A
B
C
A1 A2 A3
B1 B2 B3
C1 C2 C3
A
B
C

Figure 41. Schematic diagram of selected sampling points for dismantling of the static piles of Run 1.

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TABLE 28. SUMMARY OF BACTERIAL DATA FOR THE STATIC PILES OF RUN 1

Pile	Days Into Cycle	SAMPLE DESCRIPTION (Note: 1 m=3.28 ft)	Total Coliform (MPN/g)	Fecal Coliform (MPN/g)	Salmonella sp. (MPN/g)
-	-	Sample of Dry Compost used to cover piles	4.5×10^3	8.1×10^2	4.0×10^2
1	Start	Composite Sample taken at start	6.8×10^7	1.7×10^7	1.5×10^6
	5	External Sample (top)	2.6		
	5	Internal Sample taken with shovel	3.4×10^4		
	13	Condensate Sample from water trap	2.1×10^4	2.1×10^1	1
	19	Internal Sample taken at 1.5 m depth with auger	<2.0		
	30	Internal Sample taken at 0.3 m from top	6		
	30	Internal Sample taken at 0.8 m from top	<0.7		
	30	Internal Sample taken at 1.7 m from top	2		
2	Start	Composite Sample taken at start	3.1×10^7	3.1×10^7	2.1×10^5
	6	External Sample (top)	3.4×10^4		
	6	Internal Sample taken with shovel	6.6×10^3		
	10	Internal Sample taken at an area of high temp.	5.4		
	10	Internal Sample taken at an area of high temp.	<2.5		
	14	Condensate Sample from water trap	9.3×10^1	1.5×10^1	<1
	20	Internal Sample taken at 1.5 m depth with auger	<2.2		
	36	Internal Sample taken at 0.3 m from top	4.3×10^3		
	36	Internal Sample taken at 0.8 m from top	<1.1		
	36	Internal Sample taken at 1.7 m from top	7.9×10^1		
3	Start	Composite Sample taken at start	8.2×10^7	3.8×10^7	2.0×10^5
	4	External Sample (top)	6.1×10^4		
	4	Internal Sample taken with shovel	1.6×10^3		
	12	Condensate Sample from water trap	2.3×10^1	4	<1
	18	Internal Sample taken at 1.5 m depth with auger	2.7		
	27	Internal Sample taken at 0.3 m from top	<0.6		
	27	Internal Sample taken at 0.8 m from top	<0.6		
	27	Internal Sample taken at 1.7 m from top	<0.6		

Total solids data, however, indicated that not much drying took place within these piles. A water balance was performed up to day 26 of the operation, and it predicted that the increase in total solids content of the piles would only be 2.0, 1.7, and 0.5 percentage points for Piles 1, 2, and 3, respectively. Final total and volatile solids data collected during the dismantling of the piles can be found in Table 30. Upon inspection it seems that the water balance was correct in predicting little change in the final solids content of the piles. The solids content of the piles decreased with depth below the surface, and the sludge close to the ground was much wetter than the remainder of the pile. (Methods for drying the piles are discussed later.)

The results from this run show that static piles can produce acceptable composting performance with and without external (carbonaceous) bulking agents. Temperature elevations produced excellent microorganism kills during this run. The use of alternate bulking agents such as rice hulls and wood shavings resulted in slightly more rapid temperature elevations within these piles, less offensive odors and a faster drying rate.

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TABLE 29. SUMMARY OF BACTERIAL DATA FOR THE DISMANTLING OF THE STATIC PILES OF RUN 1

SAMPLE LOCATIONS*	PILE 1			PILE 2			PILE 3		
	Total Coliform (MPN/g)	Fecal Coliform (MPN/g)	Salmonella sp. (MPN/g)	Total Coliform (MPN/g)	Fecal Coliform (MPN/g)	Salmonella sp. (MPN/g)	Total Coliform (MPN/g)	Fecal Coliform (MPN/g)	Salmonella sp. (MPN/g)
Surface (Cover)	1.5×10^3	4.5×10^2	<0.2	860	15	2	74	16	4
A-1	3	3	<0.3	<0.9	< 0.9	<0.3	<0.9	<0.9	<0.3
A-2	<0.8	<0.8	<0.3	<0.9			<0.9		
A-3	1.3			16	16	<0.4	<0.9		
B-1	<0.9	<0.9	<0.9	<1	<1	<0.4	0.9	<0.9	<0.3
B-2	<1			<1			<0.9		
B-3	<1			<1			<0.7		
C-1	3	1	<0.3	<1	<1	<0.4	<0.9	<0.9	<0.3
C-2	<0.8			<0.9			0.9	<0.9	<0.3
C-3	<0.8			3.4			7		

* See Figure 41

TABLE 30. SUMMARY OF TOTAL AND VOLATILE SOLIDS DATA FOR THE DISMANTLING OF THE STATIC PILES OF RUN 1

	PILE 1		PILE 2		PILE 3	
SAMPLE LOCATION*	**Total Solids (%)**	**Volatile Solids (%)**	**Total Solids (%)**	**Volatile Solids (%)**	**Total Solids (%)**	**Volatile Solids (%)**
A-1	72.5	34.7	66.4	45.6	81.4	37.0
A-2	61.2	51.6	52.5	47.2	60.8	36.5
A-3	60.5	49.4	52.3	51.8	52.3	39.3
A-4	53.7	52.5	51.3	54.0	53.5	37.8
A-5	52.9	50.6	50.7	50.9	60.8	37.0
A-6	66.7	50.2	42.5	52.5	50.2	40.1
A-7	53.5	52.2	44.4	49.4	47.4	40.1
A-8	52.0	53.2	56.1	47.9	49.7	40.3
B-1	74.4	35.8	53.1	43.7	72.1	36.5
B-2	58.8	49.0	53.8	49.2	54.7	38.8
B-3	49.8	51.2	49.3	50.6	56.0	37.3
B-4	56.1	52.5	45.2	52.4	47.5	39.3
B-5	52.5	53.5	47.0	51.6	43.2	41.6
B-6	50.7	52.7	48.8	48.9	50.8	39.0
B-7	51.8	51.1	50.1	47.4	54.7	33.0
B-8	57.2	47.9	42.5	50.6	45.6	40.3
C-1	77.4	30.5	71.1	48.2	74.4	35.8
C-2	57.1	48.5	53.5	50.3	51.0	40.4
C-3	55.9	50.6	54.5	50.1	58.4	40.1
C-4	51.3	50.8	48.9	50.9	43.1	41.5
C-5	58.4	56.4	53.0	53.5	51.5	37.6
C-6	60.3	48.4	51.3	45.3	41.9	42.9
C-7	49.5	48.7	48.6	47.3	42.9	43.1
C-8	57.8	49.8	46.0	52.4	49.1	37.2

* See Figure 41 for locations of samples.

However, the slight improvements would not justify the costs of such materials. If the rice hulls and wood shavings are available at no cost, then their use would be valuable for better performance and the elimination of stockpiles of finished compost which can result in dust and odor problems.

Percent Recycle of Finished Compost

Run 3 consisted of four aerated static piles constructed with different percentages of recycled finished compost. Piles 1 through 4 contained 3.4, 2.9, 2.1, and 1.5 m^3 of finished compost per metric ton of wet sludge (4, 3.5, 2.5, and 1.8 yd^3/short tons), respectively. It was hoped to obtain an even distribution of initial solids of the piles ranging from 55 to 47.5% TS. However, due to inaccuracies in sludge mixing and pile construction, the actual initial TS contents at the start of the cycle were 57.3, 57.4, 51.5, and 52.2% for Piles 1 through 4, respectively.

The aeration system for these piles was operated in the suction mode utilizing a blower cycle time of 13 minutes on and 7 minutes off for the complete cycle, except for Piles 1 and 4. For these piles, the flow was reversed on day 24 while maintaining the same blower cycle time.

Each pile began to heat up immediately as indicated in Figure 42. By day 3 of the cycle, all piles had interior temperatures in excess of 60°C (140°F). However, although Piles 1 and 2 experienced very rapid temperature elevations, internal temperatures began to drop after day 3. Average temperatures in excess of 60°C (140°F) occurred for only 6 days. This phenomenon can be attributed to the higher initial dryness of these piles. Piles 3 and 4, however, maintained high temperatures for a longer period of time, indicating that moisture content of these piles was more near the optimum. From these results (and observations from earlier work), it appears that the optimum total solids range for good temperature elevation when utilizing only finished compost as a bulking agent is approximately 50%.

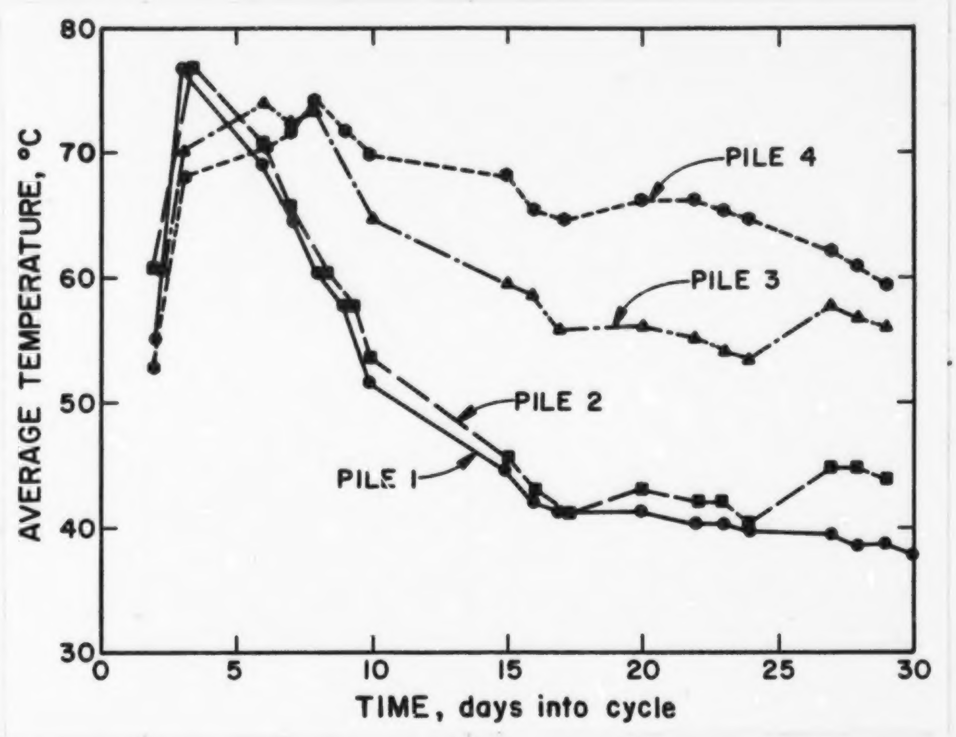

Figure 42. Average temperatures versus time for the static piles of Run 3.

Piles with low initial TS content (near 50%) experienced a temperature lag due to poor oxygen transfer caused by the excess moisture. Piles with higher initial TS content in excess of 55% heated up very quickly but did not maintain high temperatures for extended periods of time.

Information with respect to microorganism kills indicates slightly greater inactivation of coliform occurred in Piles 1 and 2. The levels of coliforms were too high in all of the piles for acceptable finished compost. Bacterial and parasite data are presented in Tables 31 and 32 for Run 3. Microorganism samples were collected during dismantling of the piles. The location of the various sampling points is presented in Figure 43. Though the dismantling of the piles occurred on different days in the cycle and final total solids contents and temperatures differed significantly within the piles, the results were somewhat similar. Complete inactivation of _Salmonella_ sp. occurred in all piles with the exception of a few locations. _Ascaris_ sp. data collected during dismantling showed high levels of viable ova in all four piles. Total coliform data were in the 10^2 to 10^5 MPN/g range for all four piles (levels within Piles 1 and 2 were in the lower end of this range). The samples collected for microbiological analysis came from the outermost portions of the piles (Figure 43), where temperatures are significantly lower than in the center of the pile. Samples near the surface were selected since they represent the areas of greatest concern for pathogenic and parasitic inactivation.

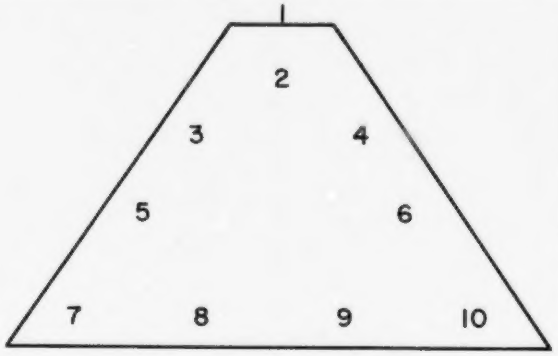

Figure 43. Schematic diagram of selected sampling points for dismantling of the static piles of Run 3.

Extended Piles and Sludge Drying Methods

A study of an aerated extended pile was conducted during Run 2. This pile was in essence a series of static piles with forced aeration, in which five separate piles were placed along side each other to make one continuous pile (Figure 44). The compost pile mixture was 2.9 m^3 of finished compost per metric ton of wet sludge (3.5 yd^3/ short ton). No external bulking agents were used in the construction of the extended pile, except for a small amount around the air lines to prevent clogging. Total and volatile solids contents of the wet cake, finished compost and subsequent blend

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TABLE 31. SUMMARY OF BACTERIAL DATA FOR THE DISMANTLING OF THE STATIC PILES OF RUN 3*

SAMPLE LOC.**	PILE 1			PILE 2			PILE 3			PILE 4		
	COLIFORM		SALMONELLA SP.	COLIFORM		SALMONELLA SP.	COLIFORM		SALMONELLA SP.	COLIFORM		SALMONELLA SP.
	Total	Fecal		Total	Fecal		Total	Fecal		Total	Fecal	
1	4.6x10^{2}	4.56	<1	2.4x10^{3}	3.3x10^{4}	1.1x10^{1}	2.7x10^{3}	8.4x10^{3}	2.6	2.7x10^{2}	2.6	<1
2	<1	<1	<1	2.3x10^{1}	<1	<1	1.0x10^{2}	<1	<1	<1	<1	<1
3	6.3	<1	<1	1.5x10^{2}	<1	<1	<1	<1	<1	3.5x10^{5}	6.3x10^{4}	<1
4	3.2x10^{1}	<1	<1	3.3	<1	<1	3.7x10^{5}	3.7x10^{5}	1.4x10^{1}	2.4x10^{3}	1.7	<1
5	<1	<1	<1		2.1	<1	6.9x10^{3}	6.9x10^{3}	1.3	<1	<1	<1
6	1.1x10^{3}	6.0x10^{2}	<1	1.1x10^{2}	<1	<1	2.2x10^{5}	2.2x10^{5}	3.0	3.7x10^{2}	1.07	<1
7	<1	<1	<1	2.4x10^{4}	2.4x10^{4}	1.0	4.3x10^{1}	<1	<1	3.4x10^{1}	<1	<1
8	1.3x10^{1}	<1	<1	<1	<1	<1	<1	<1	<1	7.3	<1	<1
9	3.3x10^{3}	<1	<1	<1	<1	<1	3.8x10^{3}	<1	<1	7.8x10^{2}	<1	<1
10	6.4x10^{1}	2.2	<1	7.0x10^{1}	<1	<1	1.4x10^{2}	<1	<1	7.6x10^{2}	1.2	<1

* All values expressed in MPN/g

** See Figure 43

TABLE 32. SUMMARY OF ASCARIS SP. DATA FOR THE DISMANTLING OF THE STATIC PILES OF RUN 3*

SAMPLE** LOCATION	PILE 1		PILE 2		PILE 3		PILE 4	
	TOTAL ASCARIS	VIABLE ASCARIS	TOTAL ASCARIS	VIABLE ASCARIS	TOTAL ASCARIS	VIABLE ASCARIS	TOTAL ASCARIS	VIABLE ASCARIS
1	-	-	<1	0	-	-	-	-
2	2	1	-	-	15	13	3	<1
3	0.5	<0.5	5	3	4	4	-	-
5	<1	<1	-	-	9	9	-	-
6	-	-	<1	0	-	-	16	5
7	13	10	2	1	-	-	-	-
8	-	-	-	-	9	2	-	-
9	-	-	-	-	-	-	-	-
10	-	-	-	-	2	<1	22	15

* Values expressed in ova/g

** See Figure 43

TABLE 33. SUMMARY OF TOTAL AND VOLATILE SOLIDS DATA* FOR START-UP OF THE STATIC PILES OF RUN 2

PILE	TOTAL SOLIDS (%)			VOLATILE SOLIDS (%)		
	Wet Cake	Finished Compost	Blend	Wet Cake	Finished Compost	Blend
1	22.5	62.8	51.4	47.9	31.5	30.7
2	26.1	65.5	52.3	46.5	30.3	31.4
3	28.8	65.6	52.4	46.4	30.2	32.6
4	23.2	62.8	55.0	49.7	32.0	32.5
5	27.5	64.8	53.5	48.6	29.1	34.1

* All values reported are averages.

mixtures for Piles 1 through 5 are given in Table 33. The total time to build the extended pile was 10 days. All of the blowers were operated continuously until temperatures began to rise and were then operated at 15 min on and 5 min off intervals (suction mode). Average air flow for Piles 1 through 5 was approximately 14 m^3/min (500 cfm) for each of the five separate blowers. Pressure drops for the five piles varied somewhat but they ranged from 11.4 to 16.5 cm (4.5 to 6.5 in) of water.

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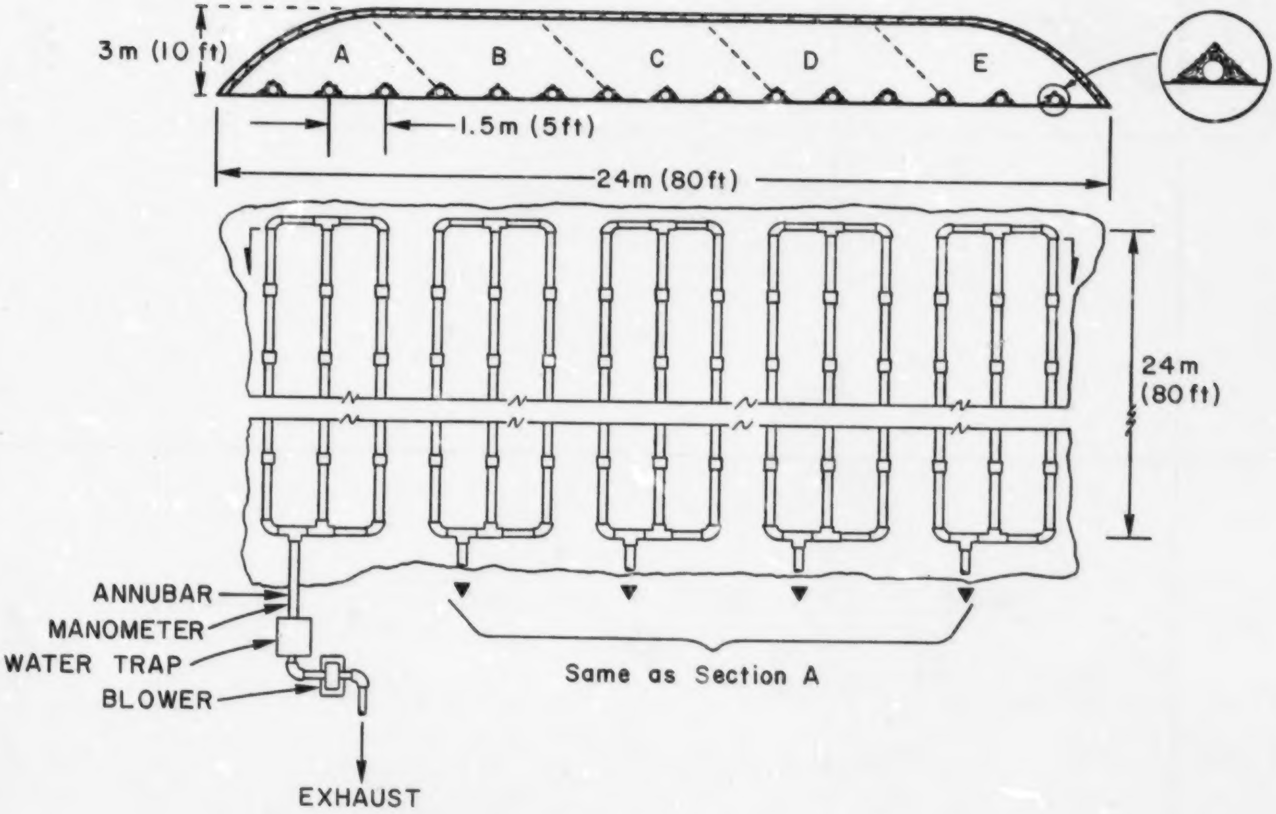
3m (10 ft)
A
B
C
D
E
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24m (80ft)
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WATER TRAP
BLOWER
EXHAUST
Same as Section A

Figure 44. Schematic diagram of the aerated extended pile.

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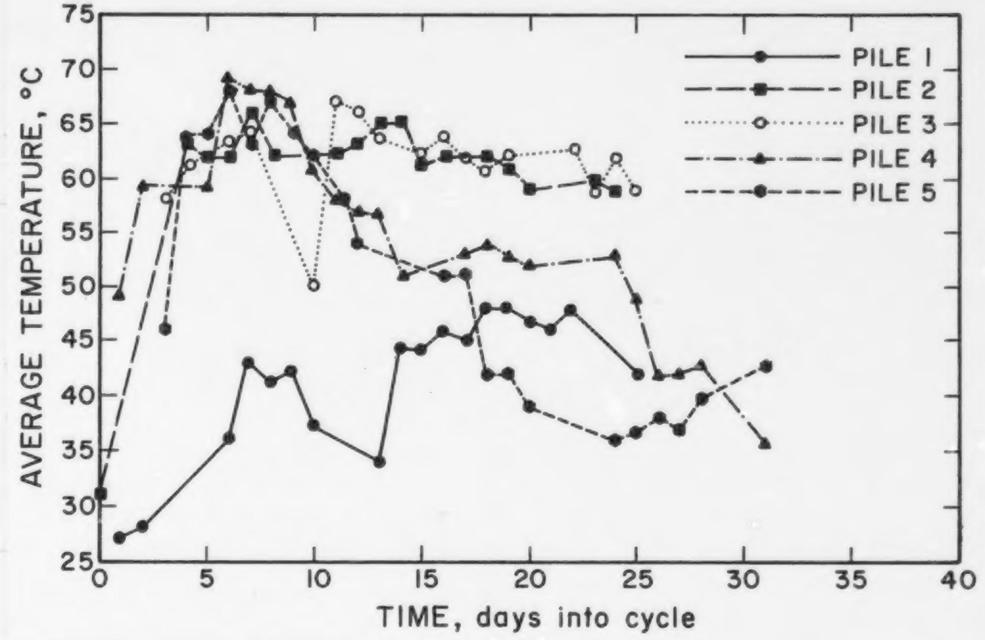

Figure 45. Average temperatures versus time for the static piles of Run 2.

The internal temperature data presented in Figure 45 shows that Piles 2 through 5 were performing well with average temperatures above 60°C (140°F) as early as 4 days into each cycle. Pile 1 did not perform as well. Temperatures in Pile 1 reached a maximum of only 48°C (118°F) while the maximum for Piles 2 through 5 were 66°C (151°F), 67°C (153°F), 69°C (156°F) and 68°C (155°F), respectively.

Piles 1, 2 and 3 were dismantled and laid in windrows to dry on day 25 of their cycles. Piles 4 and 5 were left standing in an attempt to dry them with continuous forced aeration. During the dismantling of each pile various cross-sections were cut for sampling purposes. The average total solids content for Piles 1 through 3 were 64.7, 57.2, and 55.8%, respectively. The final volatile solids content changed only slightly from the initial values. Note the higher final level of total solids within Pile 1 mentioned above. It is possible that the reason for its poorer temperature performance was due to excessive dryness within the compost material.

Data for Piles 1, 2, and 3 indicated that almost all of the microorganisms were inactivated. Average values for total coliform, fecal coliform, Salmonella sp. and Ascaris sp. for Piles 1 through 3 at the start of the compost cycle are presented in Table 34. At the completion of the run, the coliform counts were all below 10 MPN/g and the salmonellae levels below the detection limit. The final Ascaris sp. data is presented in Table 34 and indicates that the number of viable ova/g was at an acceptable level.

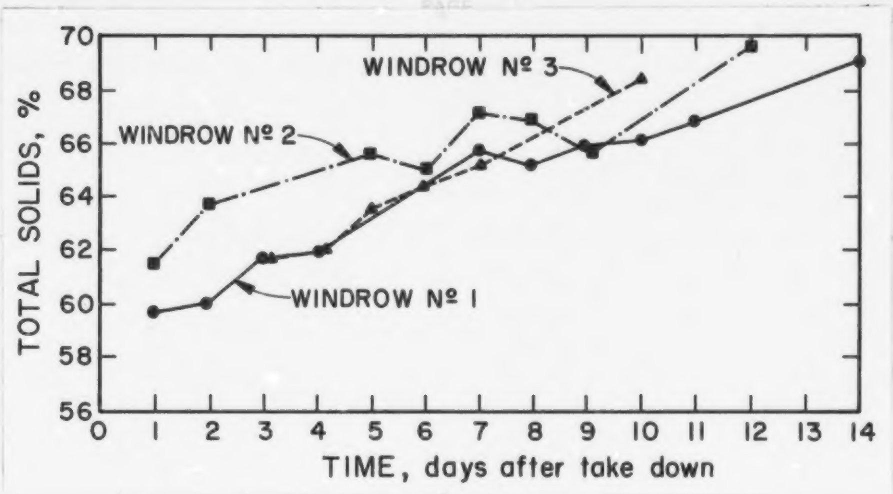

Figure 46. Total solids versus time for the drying windrows of Run 2.

Once dismantled, Piles 1, 2, and 3 were laid in windrows and monitored for total solids, volatile solids, temperature, odor concentration, and bacterial regrowth. Figure 46 is a plot of the average TS data for the drying windrows. According to this figure, the amount of drying time necessary to reach a total solids content of between 60 and 65% was only a few days. Microorganism data for these windrows indicate that some regrowth might have taken place. The relatively high moisture content and lower temperatures of 41^o to 53^oC (106 to 145^oF) within the windrows could allow microorganism regrowth. Coliform counts ranged from 10^2 to 10^3 MPN/g. Salmonella sp. did not regrow.

Static Piles 4 and 5 were dismantled on days 57 and 55 of their respective cycles. Operation of these two piles was extended in an effort to air dry them using forced aeration instead of by windrow drying. After day 26 of the compost cycle the blowers for Piles 4 and 5 were operated on a continuous basis (suction mode). It was observed that in taking down Piles 1, 2, and 3, large blocks, possibly anaerobic zones, were formed in the vicinity of the air lines. In some cases, these blocks accounted for more than half the cross section being examined. No such zones were observed in dismantling Piles 4 and 5. The average total solids content of Piles 4 and 5 was 65.4 and 66.9%, respectively. Samples from different areas of the piles ranged in total solids content from 50 to 70%. Temperatures in Piles 4 and 5 were very low during the last half of the cycle and they ranged from about 30 to 43^oC (86 to 109^oF).

Some microorganism regrowth may have occurred within piles 4 and 5 during the period of forced aeration due to low temperatures. However, there is no way of knowing whether the final microorganism counts were due to regrowth. Overall, the levels of total coliform, fecal coliform and Salmonella sp. were lower than those observed in the drying windrows of Piles 1, 2, and 3. Final microorganism counts for Piles 4 and 5 taken at the surface and 0.3, 1.2, and 2.4 m (1, 3, and 8 ft) inside the pile were

TABLE 34. SUMMARY OF MICROORGANISM DATA FOR THE STATIC PILES OF RUN 2

Piles	Initial Total Coliform (MPN/g)	Initial Fecal Coliform (MPN/g)	Initial *Salmonella* sp. (MPN/g)	Initial		*Ascaris* sp. Total		*Ascaris* sp. Viable	
				Total (ova/g)	Viable (ova/g)	Cover (ova/g)	Composite (ova/g)	Cover (ova/g)	Composite (ova/g)
1	7.7×10^7	5.1×10^6	2.0×10^4	25	6.6	0.2	4.8	<0.2	<0.7
2	7.9×10^8	4.6×10^7	1.5×10^3	17	5.0	4.5	6.9	<0.9	<1
3	1.7×10^7	3.4×10^6	1.2×10^4	6.6	3.2	-	2.5	-	<0.6

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5.1x10^3, 6x10^4, 22 and 14 MPN/g for Pile 4 and 0.3, 4.2x10^2, 5 and 16 MPN/g for Pile 5. Pile 4 had high levels of *Salmonella* sp., but the levels in Pile 5 were near the detection limit. Overall, the results of forced aeration drying of static piles were promising, but further research is needed. Results for the extended piles of Run 2 were similar to those of Run 3 with respect to microorganism kills.

For a large scale composting operation similiar to JWPCP, use of extended piles may help economize land use, however, the construction of extended piles result in more operational complexities than in the windrow operation.

Odors

In general, little odor was found to emanate from the surface of the piles in any of the three runs. The odor dilution ratio of the samples collected from the surface of the static piles (Table 35) ranged between 6 and 10. These levels are similar to the surface odor emissions from windrows. However, a significant level of odors is emitted in the blower exhaust. Maximum odor levels in the exhaust were encountered during the first week of the cycle. Typical odor emissions from static piles are presented in Table 35 for Run 2. Treatment of the blower exhaust was attempted using a pile of dry compost to scrub the exhaust. This dry compost approach was unsatisfactory for odor removal, and tended to create a back pressure on the blowers that restricted air flow. More in depth studies were conducted on odor removals from blower exhaust using water scrubbers and carbon filters for mechanical deep bin composting (6). These studies indicated that wet scrubbers and/or carbon scrubbers can be used for odor removal with much greater success than compost scrubber piles.

Several studies were performed on treating the exhaust gases from the non-enclosed mechanical system, which contained an aeration system very similar to the aerated static piles. The results are summarized in Table 36. Using finished compost material as an odor adsorbing medium was not effective. Wet scrubbers, utilizing water, potassium permanganate, sulfuric acid or sodium hypochlorite removed 40 to 60% of the odor from the exhaust gases. A two-stage scrubbing system - water scrubber followed by activated carbon - was the most effective system removing 96% of the odor.

SUMMARY

Static pile composting proved to be only marginally successful. With respect to sludge processing (operation and performance), static pile composting was inferior to the windrow composting process at the JWPCP. Some of the disadvantages of the static pile composting process were:

1. Non-uniform microorganism kills observed throughout the piles due to the difficulty in heating all portions of the pile and the short circuiting of air flow through the pile. These problems are compounded by the static (non-mixed) nature of the piles.

TABLE 35. SUMMARY OF ODOR DATA FOR THE STATIC PILES OF RUN 2

ODOR DILUTION RATIO	COMPOSTING PILE										DRYING WINDROW		
	1		2		3		4		5				
	Top of Pile	Exhaust	Top of Pile	Exhaust	Top of Pile	Exhaust	Top of Pile	Exhaust	Top of Pile	Exhaust	1	2	3
Geometric Mean	8	19	9	56	10	50	7	30	6	27	4	3	5
Maximum	23	90	60	750	26	510	35	450	20	710	10	14	35
Minimum	3	7	2	7	3	7	< 1	3	1	2	1	1	2
Number of Samples Analyzed	17	17	18	18	17	17	18	19	16	17	12	8	8

2. Difficulty in drying the piles which required extended processing time for windrow or forced aeration treatment. Microorganism regrowth may have occurred due to the combination of non-uniform microorganism kills, high moisture content and low temperatures present during the extended drying portion of the process.

3. There is a need for water scrubbers and carbon filters for treatment of the blower exhaust from the piles. The exhaust from a forced-aerated static pile contains a great deal of odor, and this point source must be treated. Left untreated, odors released from static piles can be greater than from windrows.

4. Static piles can be constructed using only recycled sludge compost, avoiding the expense of wood chips (or other additives) and the need for a screening operation. The initial total solids content of these piles should be approximately 50%.

TABLE 36. EFFECTIVENESS OF ODOR SCRUBBING TECHNIQUES ON EXHAUST GASES FROM AERATED COMPOST SYSTEMS

Odor Removal Technique	Number of Test Runs	Average Odor Removal, %
WET SCRUBBERS		
Water	13	43
$KMnO_4$	8	61
H_2SO_4	4	57
N_aOCl	8	45
ADSORPTION FILTERS		
Finished Compost	21	33
Activated Carbon	17	94
WET SCRUBBER FOLLOWED BY ACTIVATED CARBON	17	96

REFERENCES

1. Iacoboni, M.D., T.J. Le Brun, and J.R. Livingston. "Deep Windrow Composting of Dewatered Sewage Sludge." In: Proceedings of the National Conference on Municipal and Industrial Sludge Composting, Haz. Mat. Control Research Institute, Philadelphia, Pennsylvania, 1980. pp. 88-108.

2. "Standard Methods for the Examination of Water and Wastewater." 14th Edition, American Public Health Association, Washington, D.C. (1975).

3. D'Aoust, J.Y., and J. Pivnick. "Small Infectious Doses of *Salmonella*." Lancet, 1:866, 1976.

4. Lipson, A. "Infecting Doses of *Salmonella*." Lancet, 1:969, 1976.

5. Russ, Charles, F. "*Salmonella* Regrowth in Composted Sludge," Applied Microbiology, March 1981.

6. LeBrun, T.J., M.D. Iacoboni, and J.R. Livingston. "Overview of Compost Research Conducted by the Los Angeles County Sanitation Districts." In: Proceedings of the National Conference on Municipal and Industrial Sludge Composting, Haz. Mat. Control Research Institute, Philadelphia, Pennsylvania, 1980. pp. 109-116.

7. Epstein, E., G.B. Willson, W.D. Burge, D.C. Mullen and N. Enkiri. "A Forced Aeration System for Composting Wastewater Sludge," J. Water Poll. Control Fed. 48:4, 1976.

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APPENDIX

THE FATE OF VIRUSES DURING COMPOSTING OF SEWAGE SOLIDS - A REVIEW OF THE PROBLEM AND RESULTS OF FIELD STUDIES

William A. Yanko, Charles D. McGee and J. Steven Glass

INTRODUCTION

The potential for transmission of viral diseases through sludge reuse programs is probably the most poorly defined of the pathogen considerations associated with composting. It is known that over 100 antigenic types of pathogenic viruses are excreted with fecal material. The best known of these is poliovirus. However, development of a vaccine effectively eliminated poliomyelitis as a major public health concern. Currently the most important virus-related infectious agent associated with sewage is the agent of hepatitis; the other enteric viruses are often the etiologic agents of many non-specific diseases and infections.

Increased disposal of digested sludge by land application increases the possibility of public exposure to pathogenic viruses in the sludge. It must be assumed that raw sewage contains all the enteric organisms present in the population contributing to the wastewater collection system. Any enteric viruses that survive treatment processes could be available to infect personnel working with the waste material. Subsequent spread of the virus through the surrounding population is then possible. Further, contamination of edible plant parts by viruses present in sludge used as fertilizer could result in direct infection of the general population (1).

The presence of enteric viruses in raw sewage has been repeatedly demonstrated (2,3,4,5,6). Lund (2) centrifuged sewage samples and separately assayed the solids pellet and supernate. Sixty percent of positive isolations were from the solids pellet, indicating that more than half of the viruses in raw sewage are solids associated. This conclusion was supported by observations made by Lund (3) and Wellings (6), who consistently found high percentages, ranging from 16 to 100%, of enteroviruses in precipitates of wastewater treatment processes. In vitro studies by Moore (7) showed that poliovirus will adsorb to natural or artificial suspended solids, both organic and inorganic, in the presence of divalent cations. Schaub (8) observed the same adsorption tendency with encephalomyocarditis virus, and went on to demonstrate that virus adsorption is further enhanced by acidic pH. Both investigators noted that adsorption of virions to solids particles did not render the viruses non-infective, and cautioned against equating "virus removal" with "virus inactivation." From the foregoing studies, it can be concluded the infective viruses attached to solids in raw sewage become concentrated in the sludge which is removed during wastewater treatment (1, 4, 9). In fact, raw sludge from treatment plants has been frequently shown to contain viable enteric viruses (2,4,6). Hence, it is certain that viruses are carried with sludge solids to anaerobic digestion.

The anaerobic digestion process does not completely inactivate enteric viruses. Lund (2) isolated viable viruses from seven percent of samples of sludge from the Nasetverket treatment plant (Gothenburg, Sweden) which had been subjected to 50-60 days of digestion at 50°C. Palfi (10) recovered reoviruses, Echovirus type 11, and Poliovirus type 3 from digested sludges. Positive isolations were found in 38 percent of samples treated by normal digestion (21 days, 30°C) and in 13 percent of samples treated by three-stage digestion at 33°C. Infective viruses were isolated by Wellings (6) from liquid digested sludge and from digested sludge which had been sun-dried for 13 days; all viruses found in the dried sludge were identified as Echovirus type 7. Subrahmanyan (4) also found viable enteric viruses in seven percent of samples of liquid digested sludge from 5 different treatment plants in Canada, and noted that 70 percent of the isolates were reoviruses. In laboratory storage experiments he found that reoviruses can survive in digested sludge for more than six weeks, while polioviruses, coxsackieviruses, and echoviruses remained infective for several weeks in digested sludge held at room temperature. In laboratory studies using bench-scale anaerobic digesters, Bertucci (9) found that poliovirus, coxsackievirus and echovirus were removed from sludge at a rate of approximately one $\log_{10}$ per day during digestion at 35°C. He cautioned against unconditional extrapolation from bench-scale to full-sized digesters. However, similar removal rates were observed by Eisenhardt (11) studying Coxsackievirus B3 dosed into a working municipal anaerobic digester. She noted a 0.4 $\log_{10}$ reduction per day during digestion at 32°C and a 2.0 $\log_{10}$ reduction per day during digestion at 35°C. Her conclusion was that normal digester operation is insufficient to inactivate all viruses present in raw sludge. Recent work by Ward (12) and Fenters (13) indicated that ammonia concentration was a major factor influencing virus removal during anaerobic digestion. Sanders (14) reported that temperature, total solids, volatile solids and detention time all affected the recovery of poliovirus during laboratory experiments with digested sludge. However, in spite of many factors apparently detrimental to virus survival, it must be assumed that anaerobically digested sludge contains infective viruses.

Much less information is available concerning the survival of viruses in subsequent treatment processes such as drying or composting of the digested solids. Ward (15) reported that evaporation effectively reduced polio virus levels in sludge due to degradation of the RNA molecules. He suggested that drying may be a feasible method of inactivating all enteric virus in sludge. This possibility was further supported by studies conducted at the Los Angeles County Sanitation Districts for the LA/OMA Project (16). Survival of indigenous viruses was monitored during studies designed to evaluate the effectiveness of lagoons and drying beds as dewatering methods. Viruses were consistently isolated from the influent sludge but no viruses were detected in the sun dried cake samples.

Composting is another method commonly used to reduce moisture levels and stabilize organics while generating high temperatures. The heat inactivation of enteric viruses in dewatered sludge was described by Ward (17). He found that certain substances in sludge provided a protective effect and altered the rates of heat inactivation. It was suggested that these substances may significantly affect the rates of heat inactivation of enteric viruses in composted sludge. Burge (18) reported on the survival of f2 bacteriophage during composting at Beltsville, Md. High levels of phage were seeded into field composting systems and their survival monitored during the composting process. The authors found that the phage viruses could be reduced by as much as six orders of magnitude but they were not totally eliminated. The method of composting was found to influence the rate of inactivation. It should be noted that some question exists regarding the appropriateness of coliphage as an indicator for the enteric viruses. Diaz et al. (19) looked at the survival of polio viruses and f2 bacteriophage seeded into composting systems and observed rapid die-off of the viruses. The authors concluded that compost would pose very little, if any, health hazard from disease-causing viruses if used in agriculture. They noted, however, that they had experienced difficulties with the laboratory procedures used for the detection of polio viruses during the study and further questioned the validity of the f2 phage as an indicator.

When digested sludge is applied to land, viruses present in the sludge come into contact with soil particles. Recent studies have demonstrated that viruses will adhere reversibly to soil particles. Young (20), using columns of sandy- and clay-type Hawaiian soils, found that Poliovirus type 2 remained in the soil after percolation of virus-dosed tap water through the columns. Clay soils retained 96-99 percent of dosed viruses, while sandy soil retained 22-35 percent of virus dose. In another study, Lefler (21) demonstrated that attached Poliovirus type 1 could be eluted from sand during repeated washings with distilled water. Working with Poliovirus type 1 in loamy fine sand forest soil, Duboise (22) noted that most viruses adsorbed to soil particles in the top 2 cm of a 20 cm long soil column during percolation of dosed distilled water or secondary treatment plant effluent. He further found that percolation of sterile distilled water through the columns resulted in migration of viruses toward the bottom of the columns with 0.6-2.4 percent of the adsorbed dose being recoverable in the water after percolation. Intermittent elution of the dosed columns yielded higher virus desorption rates than continuous elution. Also, basic pH elution more efficiently desorbed viruses than did acidic pH elution. These observations led him to conclude that rainfall could be a major factor in the dispersion of viruses through soils. Schaub (23) found that polioviruses and encephalomyocarditis viruses adsorbed to silty sand from a rapid infiltration basin used for wastewater renovation. Retention of naturally occurring viruses in wastewater by the basin was on the order of 90 percent, as estimated from virus recovery from wells in the immediate area. Similar results were seen by Wellings (24). In one study (24) naturally occurring viruses in treated wastewater were applied to sandy soil. Only after a heavy rain were viruses recovered from surrounding wells, and then in relatively small numbers. Data from studies on a Florida cypress dome used for wastewater infiltration (5) confirmed the previous results. Repeated sampling of wells in the immediate area yielded

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only three virus isolations, a miniscule fraction of the viruses applied to the dome with wastewater. Finally, Gilbert (25) found that over 99.99 percent of viruses applied with wastewater to filtration basins at Flushing Meadows in Phoenix, Arizona, were retained in the sand and clay soil of the basins. Gerba (26) summarized factors influencing virus adsorption to soil. Adhesion is apparently based on the electronegative properties of virions and is favored by acidic pH, the presence of cations and high soil moisture. He cautioned that adsorbed viruses are not necessarily inactivated. Also, virus adsorption to soil particles does not render the viruses immobilized from the liquid phase, since alteration of soil conditions can allow the release and migration of virus particles. Vaughn's (27) work appeared to confirm this. Viruses were repeatedly isolated from wells on Long Island that had been infiltrated by poorly disinfected effluents.

The survival of soil associated enteric viruses has been under investigation since 1958. Murphy (28) found that mouse encephalomyocarditis viruses survived longer than six weeks in neutral soil, three to four weeks in alkaline soil, and less than 24 hours in acid soil. In the same study, poliovirus survived five to six weeks in loamy soil. High soil moisture, low soil temperature, neutral pH and high organic content were found to prolong the survival of poliovirus, echovirus, and coxsackievirus for as long as 150-170 days in a study by Bagdasar'yan (29). Poliovirus type 1 was shown by Lefler (21) to survive in sterile sand for 77-91 days, depending on soil moisture. Duboise (22) noted a temperature dependence of poliovirus survival in loamy sand. At 4°C viruses remained infective for more than 84 days, while at 20°C a reduction in titer of five $\log_{10}$ was observed after 84 days. Similar results were obtained by Tierney (30), investigating poliovirus survival in vegetable garden soil. During winter months, he found that viruses survived 89-120 days after application to soil. During warmer spring months, survival was limited to 8-11 days after application. Using Florida cypress dome soil, Wellings (5) demonstrated that naturally occurring poliovirus applied with wastewater survived at least 28 days during percolation through the dome. Overall, it appears that virus survival in soil is favored by high soil moisture, non-acidic pH, high organic content, and, perhaps most important, low soil temperature. Whatever the soil condition, viruses applied to land with sludges can be expected to remain infective for one to several months.

If digested sludges are to be used as fertilizer for the growth of food plants, the possibility of contamination of the plants by viruses from the sludge must be considered. After application of digested sludge to garden soil, infective viruses will be present, either adsorbed to soil particles or suspended in soil water, for a considerable length of time. Contamination of edible plant parts could occur by two mechanisms. External contamination could result from the physical adhesion of viruses to the plant. Tilling of the soil around the growing plants or soil contact by the plants while sprouting would facilitate external contamination. It is hypothesized that uptake and transport of viruses through plant root systems or vegetable skins could result in internal contamination of edible plant parts. In either instance, only fruits or vegetables that are consumed without cooking would be of major concern.

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Studying the survival of polioviruses, echoviruses, and coxsackieviruses on vegetable surfaces, Bagdasar'yan (29) found that viruses dosed onto tomato surfaces lost infectivity at the rate of one $\log_{10}$ per day at 6-10°C. Viruses on lettuce leaves were inactivated at 0.5 $\log_{10}$ per day, and survived longer than 60 days on radishes stored at 6-10°C. He pointed out that storage of contaminated vegetables at 20-23°C approximately doubled the inactivation rate of viruses on vegetable surfaces and that no penetration of viruses through vegetable skins could be demonstrated. Grigor'eva (31) found that coxsackieviruses survived longer (15-18 days) on growing tomato leaves than on growing cabbage leaves (3-4 days). Furthermore, he showed that coxsackieviruses were inactivated about twice as rapidly on tomato leaves growing in sunlight as on tomato leaves growing in shade. Poliovirus was shown by Larkin (32) to survive 14-36 days on growing lettuce and radishes after artificial contamination by spray irrigation with dosed activated sludge or secondary effluent. Tierney (30) recovered poliovirus from lettuce and radishes which had been grown in soil previously flooded with dosed sludge or secondary effluent. He estimated that the viruses survived on the growing plant surfaces for 18-23 days, and acknowledged that the viruses may have been lodged in soil particles adhering to vegetable surfaces.

To date, uptake of viruses from soil through plant roots has not been demonstrated. Toomey (33) was unable to isolate poliovirus from fruit gathered over a period of eight years, although his methodology was not notably effective. Murphy (34) succeeded in inducing laboratory grown pea and potato plant roots to incorporate tissue-associated poliovirus and mouse encephalomyocarditis virus from liquid nutrient medium. However, he observed no such virus uptake by plants grown in soil. Moreover, translocation of viruses into aerial portions of the plants was never demonstrated during his investigation.

A large scale field study of sludge applications to agricultural soils was conducted by the University of California, Riverside, for the LA/OMA project during 1976 and 1977 (35). Liquid digested sludges and composted dewatered sludges were repeatedly applied to the soil. Extensive viral testing of field and vegetable crops grown in these soils did not yield any positive virus isolations (36). Infective viruses were demonstrated to be present in the digested liquid sludges before application to the soil; none were isolated from the compost although one infective virus was detected in compost amended soil.

In summary, the review suggests that viruses do present a potential health hazard associated with sludge recovery systems and reuse programs. As with the other pathogenic organisms, the sludge must be appropriately managed to minimize these concerns, and produce a final product that is safe for the user. With this goal in mind, the Sanitation Districts of Los Angeles County has been conducting monitoring and research programs designed to assess the potential risk associated with sewage sludge compost and optimize the composting process to assure adequate pathogen control. This report summarizes the findings from approximately 3 years of examining the fate of indigenous enteric viruses in compost.

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MATERIALS AND METHODS

Composting Systems and Sampling Sites

Windrow Composting --
The standard field composting system used at the Sanitation Districts of Los Angeles County was subjected to some modification during the course of this study. The basics of the system, however, were consistent. Raw sludge from the 350 MGD advanced primary treatment Joint Water Pollution Control Plant (JWPCP) located in Carson, California, was stabilized by high rate mesophillic anaerobic digestion (15 day detention time). The digested sludge was mechanically dewatered by scroll centrifuges or high speed basket centrifuges, or a combination of both, to a TS in excess of 20%. The dewatered sludge was mixed with previously composted sludge in approximately equal volumes to adjust the initial moisture content and provide bulk to the compost mass. The wet to dry mix ratio was varied in designated windrows for research purposes. Other bulking agents, such as rice hulls and sawdust, were also evaluated. The mixed sludges were formed into windrows. The windrows were mechanically turned once each day to maintain aerobic conditions, promote drying and expose all material to the high internal temperature. The temperature typically reached 50-60^{o}C, through the activity of thermophilic microorganisms. The turning frequency was varied in designated research windrows. Composting was terminated when the TS reached approximately 60%. The completed windrows were combined into a stockpile from which material was withdrawn for use as the base for a commercial soil conditioner, with the remainder of the material recycled for use as a bulking agent.

In Vessel Composting--
This composting system consisted of large 3m x 3m x 3m (10 ft x 10 ft x 10 ft) insulated bins with a forced aeration system. The dewatered sludge mixture was piled into the bins, the bins were closed and air was drawn through the pile. The contents were mechanically mixed approximately every 7 days. High temperatures were generated but significant drying did not occur.

Aerated Static Pile Composting--
This system consisted of static piles in which sludge composting was accomplished by utilizing forced aeration to supply the necessary oxygen. Eight to ten foot piles were formed and covered with an insulating layer of dry compost. Minimal drying occurred within the piles.

Virus Sampling and Concentration--
The procedures used for detecting viruses in compost have been described in detail elsewhere (37). Briefly, a 20 to 25 g (dry weight) sample was weighed into 400 ml of 3% beef extract. In the case of a liquid sample, beef extract was added directly to the sludge at 12g/400 ml sample. The mixture was homogenized with a Polytron mixer (Brinkman Instruments) and disrupted by sonic treatment (Lab-Line model 9100 ultrasonic generator with model 9106 horn) at 170 W for 2 min without pH adjustment. Solids were then removed by centrifugation at 20,000 x g for 20 min. The beef extract eluate was then concentrated by the organic floculation method (38). The final concentrates, which averaged 8 to 12 ml, were detoxified with dithizone in chloroform (37).

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Virus Assay--

Concentrates were inoculated onto monolayers of BGMK and HEp2 cells grown on glass tubes with Eagle minimum essential medium supplemented with 10% fetal bovine serum. Tubes were examined for cytopathic effect (CPE) for a period of two weeks. Cells showing CPE were passed to a new monolayer of the same cell line for confirmation of viral CPE. Samples were recorded as positive or negative for the detection of viruses. The detection limit for these experiments varied somewhat depending on the amount of solids processed and the final volume of the concentrate. In general, however, the average detection limit was approximately 0.25 infective units (I.U.)/g dry solids.

After the first year, use of the HEp2 cell line was discontinued. No viruses were isolated on the HEp2 cells that were not also detected on the BGM line. It was therefore decided that for the purposes of this study, the extra work of culturing two cell lines was not warranted.

The concentration of viruses was determined for some samples. In these cases, the concentrates were assayed by the plaque method on monolayers of BGM cells grown on 25 cm^2 plastic flasks under Eagle's MEM with 10% fetal bovine serum (39).

Coliform MPN tests were performed as described in Standard Methods 14th ed. and final results were expressed per gram solids.

RESULTS

The first set of field experiments described in this report are from a windrow composting experiment in March of 1977 (Run 6). Two windrows were formed and composted for twenty-five days. At the time of the experiments, the scroll and basket centrifuges were run in series with the scroll centrate becoming the basket feed. The starting mixtures were 1:1 volume blends of compost and cake. Windrow 1 was turned once daily and Windrow 2 was turned twice daily. As seen in Tables 1 and 2, these windrows never achieved typically high temperatures. There were occasional rain showers during this period which may have contributed to the difficulties. Due to the nature of the cake, it also appears that the windrows were never adequately aerated. Fecal coliform levels changed very little during the twenty-five days of composting and viruses were isolated throughout the cycle.

At the end of April, 1977, Run 6 was repeated. These windrows, Run 7, were also designated Windrows 1 and 2 and were 1:1 volume blends of cake and compost and were turned one time each day. Reasonably heavy rain occurred during this period. The results of this experiment, which are summarized in Tables 3 and 4 indicate that effective composting was taking place but slowed after approximately two weeks. Viruses were isolated from the final samples but were not isolated from earlier samples taken during the cycle. There were problems, however, with the virus assay system during this period and it is felt that these difficulties contributed to the earlier negative virus isolations since viruses cannot "regrow."

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In the next series of experiments, only initial and final samples of each composting cycle were assayed. Table 5 summarizes the results for numerous windrow composting cycles during mid and late 1977. Virus survival occurred in two of seventeen final samples. One of the positive samples correlated with a high coliform count while the other occurred in a low coliform sample. Viruses were isolated in all of the samples collected at the beginning of the cycles.

Deep pile in-vessel composting experiments were started in late 1977. As can be seen in Table 6, the virus isolations correlated reasonably well with the fecal coliform data. Viruses were isolated in eight of nine starting samples and seven out of twenty-two final samples. High coliform levels were observed in five of the seven virus positive final samples. Twelve of the final samples were negative for virus and one of the positive samples had coliform levels below test detection limits (0.7 MPN/g); two of the virus negative samples contained fecal coliform levels greater than 100/g.

Table 7 summarizes the results for a series of finished windrow compost and stockpiled compost samples collected during the fall of 1977. These samples were considered to be representative of the daily composting operation at the JWPCP during that period. Viruses were isolated from three of the seventeen samples listed in Table 7. Two of the three isolates were determined to be distinct from the polio virus used experimentally in the laboratory.

After some modification in the routine field handling procedures, stockpile sampling was initiated again in the spring of 1978 through 1979. Test results for samples collected from a stockpile on the JWPCP site and another stockpile located at the fertilizer company are summarized in Table 8. Viruses were isolated from two of the 62 samples collected at JWPCP and none were found in 25 samples from the fertilizer company. Fecal coliform populations ranged greater than six orders of magnitude.

DISCUSSION

As mentioned early in the review, the virus question may be the least understood of the pathogen problems associated with sludges. There are two primary reasons for this: 1) methodologies are still relatively developmental and, 2) few environmental laboratories have the staff or facilities to perform virus and tissue culture work. A major factor which also warrants consideration when attempting to evaluate the available data is the efficacy of the methods used and the extensive reliance on experiments using artificially seeded viruses. Although these experiments are important for attempting to delineate viral-environmental relationships, studies in pilot plant tertiary treatment systems at the Sanitation Districts indicated that virus removals measured with high concentrations of seed virus did not always reflect the fate of indigenous viruses in the water (40). This suggests that one must exercise great caution when attempting to extend the results of seeded experiments to actual field events.

This agency decided at the outset that the best approach to determine the relative safety of composted sludges as a home garden soil amendment was to test for the actual pathogens of concern, including viruses. The development of a suitable method for detecting naturally occurring viruses in composted sludges proved to be a difficult problem. An adequate method must meet three basic criteria. First, the viruses must be separated from the solids to which they are attached; second, the viral particles must be concentrated to a small volume; and third, the final concentrate must not be toxic to mammalian cell culture systems used for assay. Approximately a year and a half of research and evaluation resulted in a method which met the requisite criteria (37, 41).

Using the cited methods, it was demonstrated that survival of indigenous viruses could occur after composting, although the rate of survival was quite low. In general, the combination of anaerobic digestion and composting inactivated the majority of the viruses in raw sewage sludge. Previous work in this laboratory (16) showed that raw primary sludge consistently contained infective viruses. The level ranged from 2 to 35 plaque forming units (pfu) per gram solids (60 to 1640 pfu/l) and exhibited the expected seasonal variation with the peak levels occurring in late summer, as shown in Figure 1. Anaerobic digestion destroyed a large number of these viruses; however, infective viruses could still be consistently isolated in digested sludge. Concentrations averaged 1.7 pfu/g solids (410 pfu/l) during the same period that the maximum levels occurred in the raw sludge. Not enough data was available to determine if this was a representative viral inactivation rate for anaerobic digestion. Dewatered, digested sludge samples have also consistently yielded virus isolations during routine qualitative testing.

Composting of the dewatered, digested solids has been demonstrated to be an effective means to further reduce the virus concentrations. Efficient composting can reduce the number of viruses to levels below the detection limit (0.25 IU/g) of the test procedure employed during this study. The difficulty lies in assuring that efficient composting consistently occurs. When environmental or operational conditions adversely affect the composting system, virus survival may occur as was seen in Tables 1 and 2.

None of the various composting systems studied were immune to this problem. Of interesting note, however, is that sludge drying to 90% solids was completely effective in eliminating viruses (16). This observation is consistent with Ward's (15) work on evaporation which was discussed in the review, but presents no panacea in solids treatment because drying was not effective in eliminating other pathogenic forms (16).

Although drying and evaporation inactivate viruses, this phenomenon is probably of limited importance during composting. The moisture is not reduced to a point where this mechanism would be effective. Many researchers feel heat is the major factor responsible for inactivating viruses during composting although this conclusion was questioned by Diaz et al (19). These authors indicated that other factors may exert a greater influence; competition, predation and destruction of nutrients were cited during a discussion of bacterial die-off but these factors would not seem to be appropriate to the question of viral inactivation.

The data presented for Run 6 in Tables 1 and 2 clearly indicate that viruses can survive during 25 days of composting if the composting mass does not achieve adequately high temperatures. The temperature rise observed during Run 6 clearly demonstrates that the system was biologically active although the metabolic rate was not sufficient to reach the higher temperatures achievable with the composting process. The level of dryness obtained in the final samples of this run were typical for final compost indicating that inadequate or incomplete composting would not insure virus inactivation even though achieving the requisite amount of moisture reduction. The results of this study imply that heat is probably the significant factor influencing virus inactivation during composting. Materials found in the sludge and other physical parameters may influence the rate of viral inactivation but this work strongly suggests that heat is the primary mechanism.

Uniform exposure of the entire composting mass to the self-generated high temperatures is critical to insure effective virus inactivation. Temperature gradients were observed at the tops and sides of the bins with the deep pile composting systems and the virus survival reflected this lack of uniformity. The windrow experiments described in Table 5 and the stockpile samples summarized in Tables 7 and 8 provide solid evidence, however, that composting can effectively eliminate viruses. Temperature gradient difficulties were compensated for by frequent, thorough turning during the compost cycle.

The stockpile data undoubtedly shows that fecal coliforms cannot be used as an indicator of virus survival in a monitoring program of stockpiled compost. Coliform data tended to be more predictive of virus survival when the samples were collected during, or immediately after composting. Environmental conditions in the stockpiles allowed coliform regrowth to occur, thus invalidating any indicator significance of the coliform population.

In summary, the data collected during this study substantiates the contention that composting is an effective means of eliminating viruses from sewage solids. At the same time the results strongly suggest that the composting procedures must be well defined with insurances that all of the composting mass is exposed to adequate temperatures. If the composting process is not properly controlled, virus survival can occur and should be considered in the ultimate disposal of the material.

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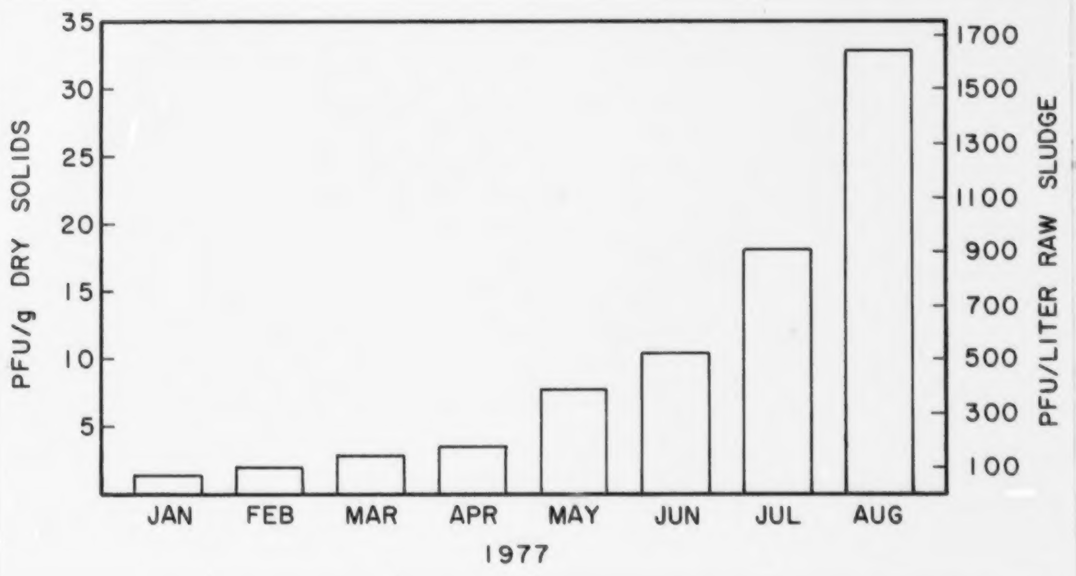

Figure 1. 1977 virus levels in raw sludge.

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TABLE 1. RUN 6, WINDROW 1 - WET CAKE AND DRIED COMPOST BLENDED 1:1 - TURNED ONCE DAILY - CENTRIFUGE IN SERIES

Date 1977	Days Composting	% Solids Ext[a]	Int[b]	Internal Temp. °C[e]	Fecal Coliform MPN/g Solids Ext[a]	Int[b]	Virus Isolation Ext[a]	Int[b]
3-21	1	42.2	47.2	18	3,400,000	3,000,000	Toxic	Toxic
3-24	4	38.6	40.1	25	8,000,000	7,800,000	+	+
3-28	8	46.5	40.5	33	1,600,000	3,500,000	+	+
3-31	11	44.5	39.2	25	690,000	1,900,000	+	+
4-4	15	51.7	54.3	24	600,000	1,400,000	+	+
4-7	18	-	52.0	40	-	250,000	+	+[d]
4-11	22	58.7	57.3	45	240,000	130,000	+[c]	+[c]
4-14	25	61.7	61.7	45	810,000	400,000	+	+[d]

a. Sample collected from exterior of windrow
b. Sample collected from interior of windrow
c. Identified as polio 1 by neutralization test
d. Non-polio 1 by neutralization test
e. Highest temp. recorded day 20, 55°C

TABLE 2. RUN 6, WINDROW 2 - WET CAKE AND DRIED COMPOST BLENDED 1:1 - TURNED TWICE DAILY - CENTRIFUGE IN SERIES

Date 1977	Days Composting	% Solids Ext[a]	Int[b]	Internal Temp. °C	Fecal Coliform MPN/g solids Ext[a]	Int[b]	Virus Isolation Ext[a]	Int[b]
3-21	1	41.6	45.5	18	1,800,000	1,700,000	+	Toxic
3-24	4	40.0	41.1	24	6,300,000	3,500,000	+	+
3-28	8	34.3	39.2	23	2,200,000	3,600,000	+	+
3-31	11	44.3	43.1	15	1,700,000	1,800,000	+	+
4-4	15	41.4	45.1	27	750,000	6,900,000	+	+
4-11	22	53.1	53.7	47	5,800	580,000	+[c]	+[c]
4-14	25	64.2	55.8	58	1,200,000	260,000	+[c]	+[d]

a. Sample collected from exterior of windrow
b. Sample collected from interior of windrow
c. Identified as polio 1 by neutralization test
d. Non-polio 1 by neutralization test

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TABLE 3. RUN 7, WINDROW 1 - 1:1 WET TO DRY BLEND - TURNED ONCE DAILY - RAIN DURING CYCLE

Date 1977	Days Composting	% Solids Ext[a]	% Solids Int[b]	Internal Temp. °C	Fecal Coliform MPN/g Solids Ext[a]	Fecal Coliform MPN/g Solids Int[b]	Virus Isolation Ext[a]	Virus Isolation Int[b]
4-21	3	41.2	51.8	48	1,800,000	2,800,000	-	+
4-25	7	51.8	52.6	61	28,000	5,900	-	-
5-2	16	62.6	65.3	56	0.4	0.4	-	-
5-5	19	58.9	58.2	52	800	4	-	-
5-12	24	55.5	60.2	47	1,700	77,000	+	+

a. Sample collected from exterior of windrow
b. Sample collected from interior of windrow

TABLE 4. RUN 7, WINDROW 2 - 1:1 WET TO DRY BLEND - TURNED ONCE DAILY - RAIN DURING CYCLE

Date 1977	Days Composting	% Solids Ext[a]	% Solids Int[b]	Internal Temp. °C[c]	Fecal Coliform MPN/g Solids Ext[a]	Fecal Coliform MPN/g Solids Int[b]	Virus Isolation Ext[a]	Virus Isolation Int[b]
4-21	3	59.4	33.4	46	6,200,000	2,300,000	-	-
4-28	10	50.2	48.4	43	210,000	99,000	-	-
5-5	19	62.6	64.3	56	1.4	2	-	-
5-12	24	61.8	55.5	45	24,000	7	+	+

a. Sample collected from exterior of windrow
b. Sample collected from interior of windrow
c. Peak temp. day 7 @ 59°C

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TABLE 5. SUMMARY OF VIRUS INACTIVATION - WINDROW COMPOSTING 1977

Starting Date 1977	Experiment	Sample Location	Total Days Composted	Highest Temp. °C	Start cycle % Solids	Start cycle F.C. MPN/g	Start cycle Virus Iso.	End cycle % Solids	End cycle F.C. MPN/g	End cycle Virus Iso.
5-17	Two stage centrifuging, 1:1 blend wet cake to dry compost, (Run 8)	Ext Int	31	54	37.0 41.0	21,000,000 17,000,000	+ +	57.4 58.6	40 0.7	- +
5-17	Two stage centrifuge cake, no bulking agent (Run 8)	Ext Int	51	65	24.6	31,000,000	+	64.4 65.0	<0.3 <0.3	- -
8-14	1:1 blend wet cake to dry compost #1	Ext Int	37	59	41.7 41.4	12,000,000 3,600,000	+ +	71.1 70.1	400 130	- -
8-14	2:1 blend wet cake to dry compost #2 (Run 9)	Ext Int	37	60	47.6 42.2	11,000,000 7,200,000	+ +	64.3 65.2	440 830	- -
8-14	2:1 blend wet cake to dry compost #3 (Run 9)	Ext Int	37	60	42.6 42.1	1,800,000 7,200,000	+ +	64.7 66.4	8 <0.5	- -
10-27	1:1 blend wet cake to dry compost (Run 10)	Ext Int	22	54	52.7	58,000,000	+	61.0 61.7	6,400 390,000	- -
10-27	1:1:1 blend wet cake to dry compost compost to rice hulls (Run 10)	Ext Int	22	60	53.0	94,000,000	+	66.7 66.0	360,000 140,000	+ -
10-27	1:1:1 blend wet cake to dry compost to redwood saw dust (Run 10)	Ext Int	22	59	44.2	330,000,000	+	62.4 58.6	740,000 790,000	- -
11-9	Static pile compost 1:2 blend cake to compost with cover	Composite	19	67	45.8	31,000,000	+	49.9	< 3	-

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TABLE 6. IN-VESSEL COMPOSTING

Starting Date	Experiment	Design Mix %TS	No. of turns	% Solids	Start Cycle F.C. MPN/g	Virus Iso.	Total days Composted	Highest temp. °C	Sample location	End Cycle % Solids	End Cycle F.C. MPN/g	Virus Iso.
10-26-77	South bin, cake and recycled compost mixed with rice hulls		none	50.7	150,000,000	+	26	68°	large ball	40.5	1100	+
									top	83.4	≥2800	+
									5' deep-side	50.4	910	+
									5' deep-middle	51.7	<0.6	-
									bottom	52.8	<0.6	-
10-26-77	North bin, cake and recycled compost mixed		none	50.4	2,900,000	+	26	66°	top	80.5	≥2900	+
									5' deep-side	46.6	≥5200	+
									5' deep-middle	56.0	<0.6	+
									bottom	57.1	<0.6	-
11-23-77	Cake and dry compost mixed		3X	50.6	2,800,000	+	27	72°	5' deep S wall,	43.3	<0.7	-
									2½' deep-middle	42.1	<0.7	-
									5' deep-middle	43.0	<0.7	-
									bottom	42.8	<0.7	-
4-26-78	Cake and dry compost mixed	45	2X	47.3	65,000,000	+	28		1' deep	49.2	<0.6	-
									5' deep	47.2	450	-
5-23-78	Cake and dry compost mixed	50	1X	42.6	21,000,000	+	20		½" deep	62.2	<0.5	+
									center	52.7	<0.5	-
									bottom	54.1	<0.5	-
8-4-78	Cake/compost blend	50	3X	45.9	5,000,000	+	19		N. bin composite	54.3	1000	-
8-4-78	Cake/compost blend	45	3X	44.7	7,000,000	-	19		S. bin composite	50.7	40	-
9-26-78	Winkle Press cake	50	2X	45.4	50,000,000	+	15		bin 1 composite	51.4	<0.6	-
9-26-78	Winkle Press cake	45	3X	42.0	6,000,000	+	30		bin 2 composite	55.0	<0.5	-

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TABLE 7. RANDOM SAMPLES OF FINISHED WINDROW AND STOCKPILED COMPOST FROM REGULAR FIELD OPERATION

Sample Date	Finished Windrow Compost % Solids	Fecal coliform MPN/g	Virus Iso.	Stockpiled Compost % Solids	Fecal Coliform MPN/g	Virus Iso.
8-25-77	NS[a]	NS	NS	62.2	<3900	-
8-25-77	NS	NS	NS	69.2	<0.4	-
8-29-77	62.9	<0.5	-	NS	NS	NS
9-1-77	NS	NS	NS	64.8	<0.5	+[b]
9-1-77	NS	NS	NS	73.4	5900	-
9-15-77	77.7	<0.3	+[c]	73.7	210	-
9-19-77	57.2	220	-	71.9	130,000	+[b]
9-26-77	67.2	50	-	69.3	<0.4	-
10-5-77	65.7	540	-	73.6	<0.3	-
10-14-77	69.8	1100	-	70.7	<0.3	-
10-17-77	64.3	29	-	69.9	<0.4	-

a. N.S. = no sample that day
b. not polio 1 by neutralization test
c. polio 1 by neutralization test

TABLE 8. STOCKPILE SUMMARY

Sample Point	Sampling Period May 1978 to November 1979 JWPCP Stockpile	Fertilizer Co. Stockpile
Total Number samples	62	25
Virus positive samples (1)	2	0
Arithmetic Mean, fecal coliform MPN/g	48,000	87,000
Geometric Mean, fecal coliform MPN/g	520	190
Median, fecal coliform MPN/g	660	23
Range, fecal coliform MPN/g	<0.4 to >4,500,000	<0.5 to >39,000,000
Mean Total solids %	63.3	62.8
Range total solids %	48.0 to 74.1	43.1 to 80.0

(1) Number of samples from which infective viruses were isolated. Theoretical detection limit ~0.025 I.U./g

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REFERENCES

1. Akin, E.W., W. Jakubowski, J.B. Lucas, H.R. Pahren. 1977. Health Hazards Associated with Wastewater Effluents and Sludge: Microbiological Considerations. US EPA, Health Effects Lab, Cincinnati, Ohio.

2. Lund, E. Observations on the Virus Binding Capacity of Sludge. Proc 5th Int. Water Poll. Res. Conf., Israel, 1971. pp. I-24/1-I-24/5.

3. Lund, E. and V. Ronne. On the Isolation of Virus from Sewage Treatment Plant Sludges. Water Res., 7 (1973): 863-871.

4. Subrahmanyan, T.P. Examination of Sewage and Sewage Sludge for Enteroviruses, Volume II. Research Program for the Abatement of Municipal Pollution. Environment Canada, Research Report No. 52, Ontario, Canada (1977).

5. Wellings, F.M., A.L. Lewis, C.W. Mountain, and L.V. Pierce. Demonstration of Virus in Groundwater after Effluent Discharge into Soil. Appl. Env. Micro., 29 (1975): 751-757.

6. Wellings, F.M., A.L. Lewis, and C.W. Mountain. Demonstration of Solids - Associated Viruses in Wastewater and Sludge. Appl. Env. Micro., 31 (1976): 354-358.

7. Moore, B.E., B.P. Sagik, and J.F. Malina, Jr. Viral Association with Suspended Solids. Water Res., 9 (1975): 197-203.

8. Schaub, S.A. and B.P. Sagik. Association of Enteroviruses with Natural and Artifically Introduced Colloidal Solids in Water and Infectivity of Solids-Associated Virions. Appl. Env. Micro, 30 (1975): 212-222.

9. Bertucci, J.J., C. Lue-Hing, D. Zenz, and S.J. Sedita. Inactivation of Viruses during Anaerobic Sludge Digestion. JWPCF, 49 (1977): 1642-1651.

10. Palfi, A. Survival of Enteroviruses During Anaerobic Sludge Digestion. In: Advances in Water Pollution Research, Proc 6th Intl Conf, S. H. Jenkins, ed, Jerusalem, 1972. Pergammon Press, New York, pp. 99-104.

11. Eisenhardt, A., E. Lund, and B. Nissen. The Effect of Sludge Digestion on Virus Infectivity. Water Res., 11 (1977): 579-581.

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U.S. GOVERNMENT PRINTING OFFICE
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12. Ward, R.L., and C.S. Ashley. Identification of the Virucidal Agent in Wastewater Sludge. Appl. Env. Micro. 33:860-864. (1977)

13. Fenters, J., J. Reed, C. Lue-Hing, J. Bertucci. Inactivation of Viruses by Digested Sludge Components. Jour. Water Poll. Control Fed. 51, 689 (1979).

14. Sanders, D.A., J.F. Malina, Jr., B.E. Moore, B.P. Sagik, C.A. Sorber. Fate of Poliovirus During Anaerobic Digestion. Jour. Water Poll. Control Fed., 51, 333 (1979).

15. Ward, R.L., and C.S. Ashley. Inactivation of Enteric Viruses in Wastewater Sludge Through Dewatering by Evaporation. Appl. Env. Micro. 34: 564 (1977).

16. Austin, S. Sludge Drying Evaporation Ponds and Percolation Beds. LA/OMA Project, LACSD, Whittier, Ca. Jan 1981.

17. Ward, R.L., and C.S. Ashley. Heat Inactivation of Enteric Viruses in Dewatered Wastewater Sludge. Appl. Env. Micro. 36: 898 (1978).

18. Burge, W.D., W.N. Cramer and E. Epstein. Pathogens in Sewage Sludge and Sludge Compost. Presented at 1976 Winter Meeting, American Society of Agricultural Engineers St. Joseph, Michigan.

19. Diaz, L.F., R.C. Cooper, L.P. Scarpace, G.J. Trezek, and C.G. Golueke. Public Health Aspects of Composting Combined Refuse and Sludge and of the Leachates therefrom. For: The State of California Solid Waste Management Board. College of Engineering. University of California, Berkeley, 1977.

20. Young, R.H.F. and N.C. Burbank, Jr. Virus Removal in Hawaiian Soils. JAWWA, 65 (1973): 598-604.

21. Lefler, E. and Y. Kott. Virus Survival and Retention in Sand. In: Proc. Cntr. Res. Water Res., Symposium No. 7, University of Texas, Austin, Texas. J.L. Malina and B. Sagik, eds, 1974, pp. 84-91.

22. DuBoise, S.M., B.E. Moore, and B.P. Sagik. Poliovirus Survival and Movement in a Sandy Forest Soil. Appl. Env. Micro., 31 (1976): 536-543.

23. Schaub, S.A. and C.A. Sorber. Virus and Bacterial Removal from Wastewater by Rapid Infiltration through Soil. App. Env. Micro., 33 (1977): 609-619.

24. Wellings, F.M., A.L. Lewis, and C.W. Mountain. Virus Survival Following Wastewater Spray Irrigation of Sandy Soils. In: Virus Survival in Water and Wastewater Systems, J. Malina and B. Sagik, eds. University of Texas, Austin, 1975. pp. 253-260.

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EPA Form 2350-4 (4-80)
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U.S. GOVERNMENT PRINTING OFFICE 1981
TYPING GUIDE SHEET

25. Gilbert, R.G., R.C. Rice, H. Bouwer, C.P. Gerba, C. Wallis, and J.L. Melnick. Wastewater Renovation and Reuse: Virus Removal by Soil Filtration. Science, 192 (1976): 1004-1005.

26. Gerba, C.P., C. Wallis, and J.L. Melnick. Fate of Wastewater Bacteria and Viruses in Soil. J. Irrig. Drainage Div. ASCE, IR3 (1975): 157-174.

27. Vaughn, J.M. and E.F. Landry. An Assessment of the Occurrence of Human Viruses in Long Island Aquatic Systems. Brookhaven National Laboratory, Associated Universities, Inc. for United States Department of Energy. Available from National Technical Information Service, U.S. Dept. of Commerce. Springfield, VA (1977).

28. Murphy, W.H., O.R. Eylar, E.L. Schmidt, and J.T. Syverton. Absorption and Translocation of Mammalian Viruses by Plants. I. Survival of Mouse Encephalomyelitis and Poliomyelitis Viruses in Soil and Plant Root Environment. Virology, 6 (1958): 612-622.

29. Bagdasar'yan, G.A. Survival of Viruses of the Enterovirus Group (Poliomyelitis, Echo, Coxsackie) in Soil and on Vegetables. J. Hyg. Epidem. Micro., 8 (1964): 497-505.

30. Tierney, J.T., R. Sullivan, and E.P. Larkin. Persistence of Poliovirus 1 in Soil and on Vegetables Grown in Soil Previously Flooded with Inoculated Sewage Sludge or Effluent. Appl. Env. Micro., 33 (1977): 109-113.

31. Grigor'eva, L.V., A.S. Gorodetskii, T.G. Omel'yanets, and L.A. Bogdanenko. Survival of Bacteria and Viruses on Vegetable Crops Irrigated with Infected Water. Hyg. Sanit., 30 (1965): 357-361.

32. Larkin, E.P., J.T. Tierney, and R. Sullivan. Persistence of Virus on Sewage-Irrigated Vegetables. J. Env. Eng. Div, ASCE, EE1 (1976): 29-35.

33. Toomey, J.A., W.S. Takacs, and L.A. Tischer. Attempts to Recover Poliomyelitis Virus from Fruit, Well Water, Chicken Cords and Dog Stools. J. Pediat., 23 (1943): 168-171.

34. Murphy, W.H. and J.T. Syverton. Absorption and Translocation of Mammalian Viruses by Plants. II. Recovery and Distribution of Viruses in Plants. Virology, 6 (1958): 623-636.

35. Chang, A.C., A.L. Page, L.J. Lund, P.F. Pratt and G.R. Bradford. Final Report: Land Application of Sewage Sludge--a Field Demonstration for Regional Wastewater Solids Management Program, Los Angeles/Orange County Metropolitan Area. Department of Soil and Environmental Sciences, University of California, Riverside, Ca. (1978).

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36. Yanko, W.A., J.S. Glass, R.J. Van Sluis, J.A. Dahlgren and R.C. Easly. Survival of Pathogenic and Indicator Microorganisms in Sewage Sludge Amended Agricultural Soils--Winter and Summer Growing Seasons 1977 for the Regional Wastewater Solids Management Program, Los Angeles/Orange County Metropolitan Area. County Sanitation Districts of Los Angeles County. San Jose Creek Water Quality Laboratory, Whittier, Ca. (1978).

37. Glass, J.S., R.J. Van Sluis and W.A. Yanko. Practical Method for Detecting Poliovirus in Anaerobic Digester Sludge. Appl. Env. Micro., 35: 983 (1978).

38. Katzenelson, E.,B. Fattal and T. Hostovesky. Organic Flocculation: an Efficient Second Step Concentration Method for Detection of Viruses in Tap Water. Appl. Env. Micro. 32: 638 (1976).

39. Dahling, D.R., G. Berg and D. Berman. BGM, a Continuous Cell Line More Sensitive than Primary Rhesus and African Green Kidney Cells for the Recovery of Viruses from Water. Health Lab. Science. 11:275 (1974).

40. Miele, R.P., Pomona Virus Study--Final Report, Sanitation Districts of Los Angeles County. (1977).

41. Van Sluis, R.J., J.S. Glass, and W.A. Yanko. The Isolation and Detection of Enteric Viruses in Dewatered Anaerobically Digested Sludge. Procedure Evaluation Results. Intradepartmental Report, San Jose Creek Water Quality Laboratory, County Sanitation Districts of Los Angeles County, Whittier, Calif. (1977).

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